LECTURE NOTES
of
AEN-121

Soil and Water Conservation Engineering

FOR BSc. (AG) STUDENTS
(BIHAR AGRICULTURAL COLLEGE, SABOUR, BHAGALPUR)

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AEN-121 Soil and Water Conservation Engineering

01	Introduction to Soil and Water Conservation, causes of soil erosion

1.1 Why Soil and Water Conservation?

Soil and water are two important natural resources and the basic needs for agricultural production. During the last century it has been observed that the pressure of increasing population has led to degradation of these natural resources. In other words increase in agricultural production to feed the increasing population is only possible if there sufficient fertile land and water are available for farming. In India, out of 328 million hectares of geographical area, 68 million hectares are critically degraded while 107 million hectares are severely eroded. That's why soil and water should be given first priority from the conservation point of view and appropriate methods should be used to ensure their sustainability and future availability. Status of global land degradation is shown in Fig. 1.1.

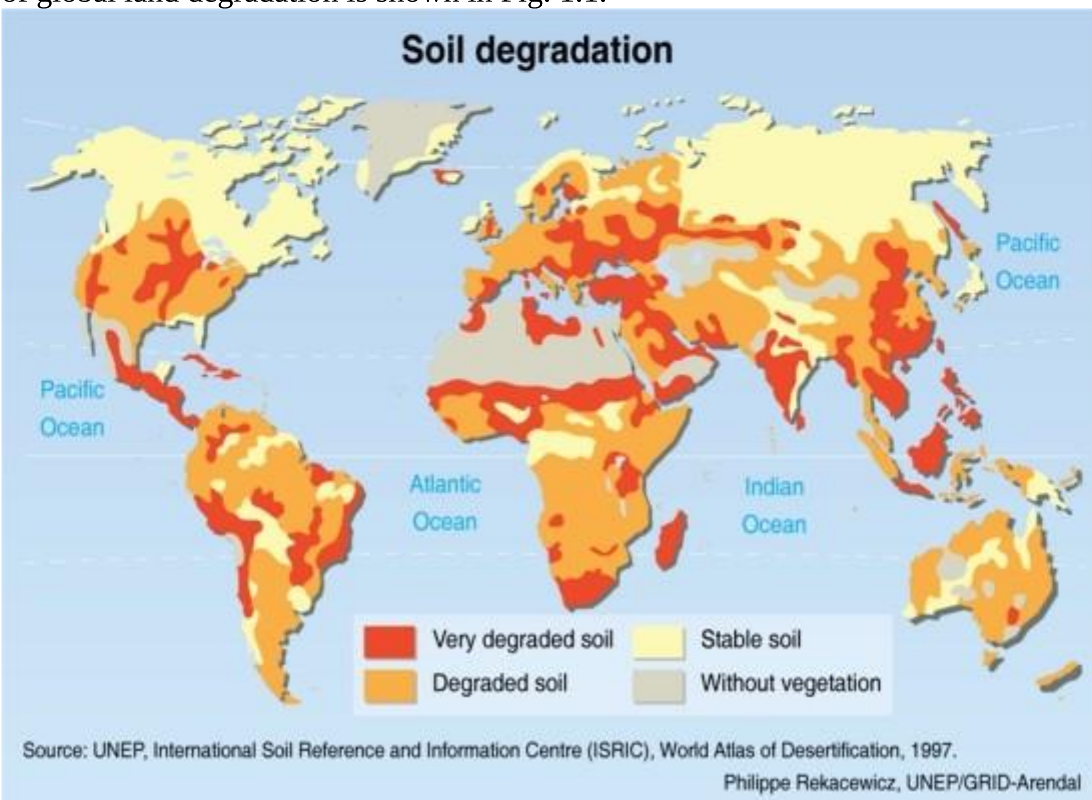

Fig. 1.1. Global soil degradation map.

Water conservation is the use and management of water for the good of all users. Water is abundant throughout the earth, yet only three percent of all water is fresh water, and less than seven-tenths of freshwater is usable. Much of the usable water is utilized for irrigation. Detailed analysis will show that in about fifteen years, about two-thirds of the world's population will be living in some sort of water shortage. Water is used in nearly every aspect of life. There are multiple domestic, industrial and agricultural uses. Water conservation is rapidly becoming a hot topic, yet many people do not realize the importance of soil conservation.

Soil conservation is defined as the control of soil erosion in order to maintain agricultural productivity. Soil erosion is often the effect of many natural causes, such as water and wind.

There are also human factors which increase the rate of soil erosion such as construction, cultivation and other activities. Some may argue that since it is a natural process, soil erosion is not harmful. The truth is that with the removal of the top layer of soil, the organic matter and nutrients are also removed.

Conservation is not just the responsibility of soil and plant scientists, hydrologists, wildlife managers, landowners, and the forest or mine owner alone.

All citizens should be made aware about the importance of natural resources as our lives depend on that and everyone should be involved in the process of caring of these resources properly and using them intelligently.

1.1.1 What is Soil Erosion?

The uppermost weathered and disintegrated layer of the earth's crust is referred to as soil. The soil layer is composed of mineral and organic matter and is capable of sustaining plant life. The soil depth is less in some places and more at other places and may vary from practically nil to several metres. The soil layer is continuously exposed to the actions of atmosphere. Wind and water in motion are two main agencies which act on the soil layer and dislodge the soil particles and transport them. The loosening of the soil from its place and its transportation from one place to another is known as soil erosion.

The word erosion has been derived from the Latin word 'erodere' which means eating away or to excavate. The word erosion was first used in geology for describing the term hollow created by water. Erosion actually is a two phase process involving the detachment of individual soil particle from soil mass, transporting it from one place to another (by the action of any one of the agents of erosion, viz; water, wind, ice or gravity) and its deposition. When sufficient energy is not available to transport a particle, a third phase known as deposition occurs. In general, finer soil particles get eroded more easily than coarse particles (silt is more easily eroded than sand). Hence soil erosion is defined as a process of detachment, transportation and deposition of soil particles (sediment). It is evident that sediment is the end product of soil erosion process. Sediment is, therefore, defined as any fragmented material, which is transported or deposited by water, ice, air or any other natural agent. From this, it is inferred that sedimentation is also the process of detachment, transportation and deposition of eroded soil particles. Thus, the natural sequence of the sediment cycle is as follows:

Soil $\longrightarrow$ detachment $\longrightarrow$ Transportation $\longrightarrow$ Deposition

Detachment is the dislodging of the soil particle from the soil mass by erosive agents. In case of water erosion, major erosive agents are impacting raindrops and runoff water flowing over the soil surface. Transportation is the entrainment and movement of detached soil particles (sediment) from their original location. Sediments move from the upland sources through the stream system and may eventually reach the ocean. Not all the sediment reaches the ocean; some are deposited at the base of the slopes, in reservoirs and flood plains along the way. Erosion is

almost universally recognized as a serious threat to human well being. Erosion reduces the productivity of crop land by removing and washing away of plant nutrients and organic matter. Distribution of global sediment load is presented in Fig. 1.2.

Fig. 1.2. Global sediment loads. Due to high monsoon rainfall, Asia has the highest suspended sediment discharge.

1.1.2 Problems Arising due to Soil Erosion

Balanced ecosystems comprising soil, water and plant environments are essential for the survival and welfare of mankind. However, ecosystems have been disturbed in the past due to over exploitation in many parts of the world, including some parts of India. The resulting imbalance in the ecosystem is revealed through various undesirable effects, such as degradation of soil surfaces, frequent occurrence of intense floods etc.

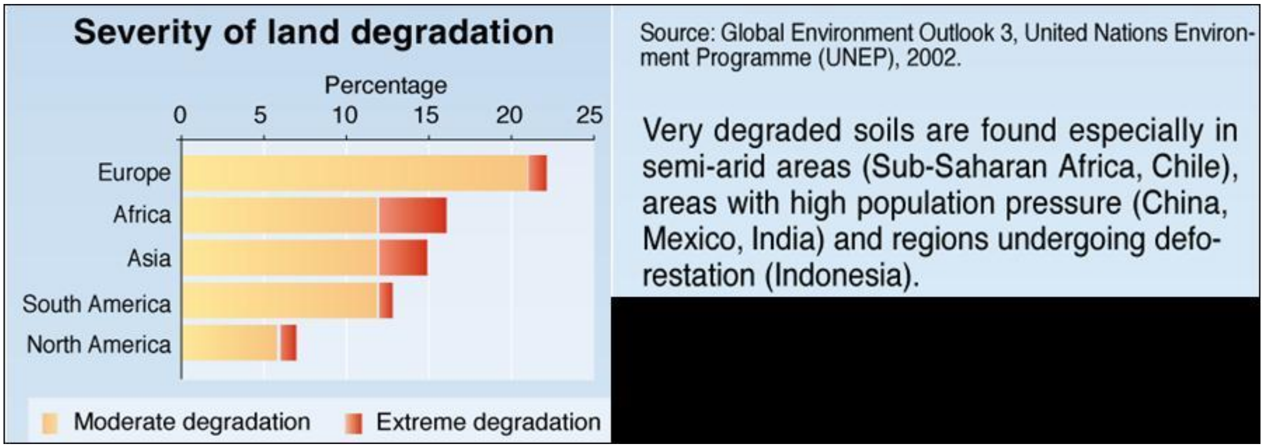

Fig. 1.3. Severity of land degradation at continental scale.

Vast tracts of land have been irreversibly converted into infertile surfaces due to accelerated soil erosion caused by the above and other factors. These degraded land surfaces have also become a source of pollution of the natural water. Deposition of soil eroded from upland areas in the downstream reaches of rivers has caused aggradation. This has resulted in an increase in the flood plain area of the rivers, reduction of the clearance below bridges and culverts and sedimentation of reservoirs. Severity of land degradation at a continental scale is shown in Fig. 1.3.

The major land degradation problems due to sedimentation are briefly discussed as below:

- Erosion by wind and water: Out of 144.12 M-ha areas affected by water and wind erosion. About 69 M-ha is considered to be critical and needs immediate attention. Wind erosion is mainly restricted to States of Rajasthan, Gujarat and Haryana. The severity of wind erosion is inversely related to the rainfall amount, lesser is the rainfall more would be the wind erosion.

- Gullies and Ravines: About 4 M-ha is affected by the problem of gullies and ravines in the country covering about 12 states. Ravines are mostly located in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Gullies on the other hand are seen in the plateau region of Eastern India, foot hills of the Himalayas and areas of Deccan Plateau.

- Torrents and Riverine Lands: Problem of Riverine and torrents is spread over an area of 2.73 M-ha in the country. Torrents are the natural streams which cause extensive damage to life and property as a result of frequent changes in their course and associated flash flows with heavy debris loads. The unfertile material or debris transported by torrents is sometimes deposited on the fertile plains, thus ruining the land for ever.

- Water logging: Water logging is caused either by surface flooding or due to rise of water table. An area of 8.53 M-ha has been estimated to be affected by water logging. Water logging due to surface flooding is predominant in the states of West Bengal, Assam, Bihar, Orissa, Andhra Pradesh, Uttar Pradesh, Kerala, Punjab and Haryana.

- Shifting Cultivation: Shifting cultivation, also known as 'jhuming' is a traditional method of growing crops on hill slopes by slash and burn method. The method involves selection of appropriate site on hill slopes, cleaning of forest by cutting and burning, using the site for cultivation for few years and later on abandoning it and moving to a fresh site. The jhum cycle has gradually declined from 20-30 years to 3-6 years due to increasing population pressures. The problem is more serious in North Eastern region and in the states of Orissa and Andhra Pradesh.

- Saline soil including coastal areas: Saline soils are prevalent both in inland as well as coastal areas. About 5.5 M-ha area is affected by this problem in the country which includes arid and semi-arid areas of Rajasthan and Gujarat, black soil region and coastal areas. This problem is causing serious damage to agricultural lands, rendering fertile soil unproductive and turning groundwater brackish in the States of West Bengal, Tamil Nadu, Orissa, Maharashtra, Kerala, Karnataka, Gujarat and Andhra Pradesh as well as Union Territories of Pondicherry and Goa, Daman and Diu.

- Floods and Droughts: In India, among the major and medium rivers of both Himalayas and non-Himalayas catagories, 18 are flood prone which drain an area of 150 M-ha. In recent years, flash floods have caused extensive damage even in the desert areas of Rajasthan and Gujarat.

1.1.3 Importance of Soil Conservation

In India, out of the total geographical area of 329 M-ha, an area of about 150 M-ha is subjected to either water or wind erosion. A net area of about 140 M-ha is cropped at present. An area of 40 M-ha is considered to be flood prone. Area lost through ravines and gullies is estimated to be about 4 M-ha. As a whole, it is estimated that about 175 M-ha i.e., 53.3% of the total geographical area of the country is subjected to various soil and land degradation problems like saline-alkali soils, waterlogged areas, ravine and gullied lands, area under shifting cultivation, and desertification. By the year 2100 A.D, the projected population of the country is expected to be two billion, whereas the food grain production is almost stagnant at 211 million tons for the last 5 years. The per capita cropped area is shrinking every day; in the year 1950, it was 0.33 ha/capita, 0.2 ha in 1980 and it was 0.15 ha by 2000. This clearly shows that the limited land resource has to be managed very carefully by adopting total conservation measures for the survival of the huge population. A few suggestions to conserve soil and water resources in Indian context are discussed below.

- To prevent erosion of bare soil, it is important to maintain a vegetation cover, especially in the most vulnerable areas e.g. those with steep slopes, in a dry season or periods of very heavy rainfall. For this purpose, only partial harvesting forests (e.g. alternate trees)

and use of seasonally dry or wet areas for pasture rather than arable agricultural land should be permitted.

- Where intensive cultivation takes place, farmers should follow crop rotation in order to prevent the soil becoming exhausted of organic matters and other soil building agents. Where soils are ploughed in vulnerable areas, contour ploughing (i.e. round the hillside rather than down the hillside) should be used. Careful management of irrigation, to prevent the application of too much or too little water will be helpful to reduce the problem of soil salinity development. Livestock grazing must be carefully managed to prevent overgrazing.

- Construction of highways and urbanization should be restricted to areas of lower agricultural potential. With extractive industries, a pledge must be secured to restore the land to its former condition before permission for quarries or mines is granted.

1.2 Causes of Soil Degradation

Soil degradation may result from natural causes and human-induced causes. Topographic and climatic factors such as steep slopes, frequent floods and tornadoes, storms and high-velocity wind, high-intensity rains, leaching in humid regions, and drought in dry regions are among the natural causes. Deforestation and overexploitation of vegetation, shifting cultivation, soil desurfacing, overgrazing, indiscriminate use of agrochemicals and lack of soil conservation practices, and overextraction of ground water are some anthropogenic causes of soil degradation. The principal cause of land degradation is the non-appropriate land use. Economic and social problems, population pressure, poverty, land tenure system, farming systems, lack of technical advice, use of improper implements, etc. are the reasons of this mismanagement. GLASOD identified five main causes of human induced soil degradation worldwide: deforestation, overgrazing, mismanagement of agricultural land, overexploitation, and bio-industrial activities. The causes of soil degradation are elaborated in the following sections.

1.2.1 Deforestation

Deforestation refers to the conversion of a forest into a non-forest use such as farmland, ranches, pasture, industrial complexes, and urban areas. It is estimated that only about 22 % of the world's original forest cover remains For millennia, humankind has influenced the forests, and the impact has been enormous. Deforestation is expanding and accelerating into the remaining areas of undisturbed forest, and the quality of the remaining forests is declining. Deforestation processes include industrial logging, clear felling, indiscriminate cutting, forest fires, shifting cultivation, and encroachment. The effects of deforestation are loss of forest, loss of biodiversity, climate change, and natural disasters such as cyclones, flood and drought, disruption of water cycle, decline in water quality, soil erosion, and sedimentation. Forests regulate the hydrologic processes: evaporation, transpiration, infiltration, and surface flow. Cutting trees in large tracts results in the climate getting drier in that area. Forest clearance exposes the bare soil to the scorching effect of the sun and the beating action of the rains. Significant amount of top soil is lost by erosion. Due to elevated temperature, soil organic matter is decomposed at a faster rate, and soil aggregates are broken down by raindrop impact. Infiltration rate is reduced and more water runs off. Large tracts of land become permanently impoverished due to soil erosion for these reasons. Deforestation increases the carbon dioxide emission into the atmosphere. Tropical deforestation accounts for about 20 % of total global carbon dioxide (CO_2) emissions

1.2.2 Shifting Cultivation

Shifting cultivation or slash-and-burn agriculture is an ancient farming system usually practiced by the indigenous people in the hilly areas of the humid tropics. In this system, a patch of forest, usually on gentle slopes or on summits of hills, is cleared, vegetation is slashed and burned, holes are dug in soil with elementary tools, and seeds of assorted crops are sown before monsoon. Seeds germinate and grow rainfed, and the crops are harvested after 6–8 months. Then the land is left fallow. Farmers clear a new patch of forest for cultivation in the next season. Earlier, they returned to the previous land for cropping after 15–20 years, but the rotation period has now alarmingly squeezed to less than 3 years. Overpopulation, settlement of plain landers to hills, and scarcity of available land for cropping are behind this shrinkage. This has enhanced deforestation, loss of biodiversity, and soil degradation.

Shifting farmers burn the slashed debris so that nutrients in its ash should increase fertility and enhance crop productivity. The effect of burning is, however, temporary. Rains following burning remove bases rapidly by erosion and leaching. Growing evidence suggests that shifting cultivation in its distorted form leads to an adverse effect on soil and water. Such activities affect soil physical and chemical properties, reduce nutrient stocks, and accelerate soil erosion and sedimentation.

1.2.3 Overgrazing

Overgrazing is a major cause of soil degradation worldwide. Overgrazing is the most devastating cause of desertification in arid lands. Livestock are the main source of income in many arid and semiarid countries. Domestic stocks are widely diverse and consist of camels, donkeys, horses, cows, sheep, and goat. The forage and overgrazing of livestock cause a chain of degradation, critically reducing vegetation cover and soil fertility, as well as increasing erosion. Domestic animals rapidly clear vegetation, placing stress on a land that already has a low vegetation cover. They also move in large groups and have sharp hooves that easily break up the soil, leaving it susceptible to erosion. Erosion decreases fertile organic content of the soil. The lack of organic matter can lead to desertification through reduced nutrient availability for plant growth.

1.2.4 Soil Desurfacing

Soil desurfacing refers to the removal of a layer of surface soil for many different purposes, including construction of road and railroads and making of bricks. Brick is an important element of urban development. The surface soil is the most fertile part of the soil; it contains the highest organic matter and nutrients and possesses the most suitable physical and chemical conditions for plant growth. Soil desurfacing decreases organic matter, nutrients, and available water, and the exposed subsoil is more compact. Soil desurfacing significantly reduces soil quality and crop yields.

1.2.5 Monocropping

Monocropping is the practice of growing a single crop year after year on the same land, in the absence rotation through other crops. Rice, maize, soybean, and wheat are the common crops grown as monocrops. It is economically an effi cient system, but it can negatively impact the soil fertility and ecology. The roots of the crop draw the same kind and proportion of nutrients from the soil for a long period of time. The nutrient status of the soil becomes imbalanced after a

prolonged period of cropping. Particular types of insects and pests proliferate. Farmers become increasingly dependent on pesticides.

1.2.6 Mismanagement of Irrigation

It is not possible for farming to occur without artificial irrigation in arid lands where there is a deficiency of moisture. However, irrigation in arid lands can further enhance desertification through salinization and alkalinization. Salinization occurs when irrigation water evaporates quickly, leaving natural salts (chlorides, sulfates, and carbonates of sodium, potassium, calcium, and magnesium) at the surface of the soil. Over a long time, excessive quantities of salts accumulate at or near the soil surface, making it increasingly diffi cult for plants to extract water from the soil. This is because inadequate water is applied for the scarcity of water in the arid and semiarid climate. Irrigation water must consider the leaching requirement (extra water to leach the salts) of the soil.

1.2.7 Use of Heavy Farm Machineries

Heavy farm machineries are used in mechanized agriculture by the developed countries. Tractors and cultivators may weigh more than 20 tons. Such heavy loads of these machines severely compact soils. This is almost irreversible. Deep compaction below the plow layer (plow pan) is difficult to decompact. Impact of heavy farm machineries on soil degradation is discussed in more detail in connection with soil compaction.

1.2.8 Mining

Mining contributes significantly to soil pollution, especially with heavy metals. Mining is responsible for large-scale soil degradation.

2	Definition and agents of soil erosion

2.0 Definition-Soil Erosion

Soil erosion is the detachment and transportation of soil material from one place to another through the action of wind, water in motion or by the beating action of the rain drops. Although soil erosion is a physical process with considerable variation globally in its severity and frequency, where and when erosion occurs is also strongly influenced by social, economic, political and institutional factors. Conventional wisdom favours explaining erosion as a response to increasing pressure on land brought about by a growing world population and the abandonment of large areas of formerly productive land as a result of erosion, salinization or alkalinization.

The factors that influence the rate of erosion may be considered under three headings: energy, resistance and protection. The energy group includes the potential ability of rainfall, runoff and wind to cause erosion. This ability is termed erosivity. Also included are those factors that directly affect the power of the erosive agents, such as the reduction in the length of runoff or wind blow through the construction of terraces and wind breaks respectively. Fundamental to the resistance group is the erodibility of the soil, which depends upon its mechanical and chemical properties. Factors that encourage the infiltration of water into the soil and thereby reduce runoff decrease erodibility, while any activity that pulverizes the soil increases it. Thus cultivation may decrease the erodibility of clay soils but increase that of sandy soils. The protection group focuses on factors relating to the plant cover. By intercepting rainfall and reducing the velocity of runoff and wind, plant cover can protect the soil from erosion. Different plant cover affords different degrees of protection, so that human influence, by determining land use, can control the rate of erosion to a considerable degree. The rate of soil loss is normally expressed in units of mass or volume per unit area per unit of time. Under natural conditions, annual rates are of the order of 0.0045 t ha^{-1} for areas of moderate relief and 0.45 t ha^{-1} for steep relief.

There is increasing awareness of the need to protect our natural resources in order to meet present and future requirements. Since economies and environments are dependent on healthy soil and water, it is essential to ensure the sustainable use of the resource base in the face of growing demand. Excessive or enhanced soil erosion due to poor land management can result in both onand off-site impacts that are detrimental to a whole range of receptors. Where soil erosion occurs, the soil resource can be severely depleted if the rate of erosion exceeds the rate of natural soil formation. This loss often corresponds to the most agriculturally important topsoil and any fertilizer or pesticide application, causing subsequent reductions in agricultural productivity. Soil erosion is a hazard traditionally associated with agriculture, and often occurs in tropical and semiarid areas.

2.1 Types of Soil Degradation

There are five main types of soil degradation, including water erosion, wind erosion, chemical deterioration, physical deterioration, and degradation of biological activity. There are several subtypes of each type except biological degradation. These types and subtypes are mentioned below.

Table 2.1 Soil degradation types and subtypes	
Type	**Subtypes**
W: Water erosion	Wt: loss topsoil Wd: terrain deformation/mass movement Wo: off-site effects Wo: reservoir sedimentation Wof: flooding Woc: coral reef and seaweed destruction
E: Wind erosion	Et: loss of topsoil Ed: terrain deformation Eo: overblowing
C: Chemical deterioration	Cn: Loss of nutrients and/or organic matters Cs: Salination Ca: Acidifi cation Cp: Pollution Ct: Acid sulphate soils Ce: Eutrifi cation
P: Physical deterioration	Pc: compaction, sealing, and crusting Pw: water logging Pa: lowering of water table Ps: subsidence of organic soils Po: other physical activities such as mining and urbanization
B: Degradation of biological activity	

The erosion may be broadly classified into two groups:
(1) Geological/natural erosion
(2) Accelerated/abnormal erosion

Erosion is the detachment of materials from earth surfaces such as rock and soil from its original assemblage and position and transport to other places by various agents, including water, wind, glacier, and gravity. Erosion has both on-site and offsite effects. Earth materials from the mountains of the Himalayas are being torn out and carried by river systems to the Gangetic Delta through geological time. The process brings about changes in landforms of both the places. The Himalayas are weathering away and the deltas are accumulating alluviums, and the land level rises above the sea level. In many cases, frost and high temperature separate pieces of weathered rock, and the loose material moves downhill to form piles of hillside waste, debris cones, outwash fans, and other formations. This is geological erosion occurring in almost all natural surfaces through natural forces. However, erosion may be of different types, such as rock erosion, land erosion, and soil erosion, depending on the surface concerned. Erosion may be divided into natural or geologic and human-induced or accelerated erosion. Soil erosion involves two processes: detachment of particles from soil aggregates and transport of the particles by water or wind. Soil erosion in undisturbed landscapes by natural forces is called normal erosion,

natural erosion, or geological erosion which occurs almost silently and often leaves no signs. Natural erosion is not of much concern because the amount of soil loss is readily compensated by the natural processes of soil formation.

But human actions for the exploitation of land, water, vegetation, and soil resources tremendously accelerated the extent and intensity of soil erosion. This is known as accelerated soil erosion. Generally accelerated erosion is considered to be soil erosion proper. Accelerated erosion occurs usually at an alarming rate that reduces soil quality and crop yield on-site and damages land, water, and installations off-site.

Agents of Soil Erosion:

1. **Water erosion**: water erosion is the removal of soil from the land's surface by running water, including runoff from melted snow and ice. Depending upon the form of the lost soil, water erosion is subdivided into Sheet, Rill and Gully erosion.
    a) Sheet erosion: It is the uniform removal of soil in thin layer from sloping land. This results from sheet or overland flows, the runoff from the surface in thin layer (although important, sheet erosion in unnoticed because it occurs gradually). The beating action of raindrops combined with surface flow causes the major portion of the sheet erosion. From an energy stand point, raindrop erosion is far more important because raindrops have velocity of about 20 to 30 feet per second where as overland flow velocities are about 1 to 2 feet per second. Raindrops cause the particles to be detached and transported and the increased sediment reduces the infiltration rate by scaling the soil pores. Areas where loose, shallow topsoil over lies a tight sub soil are most susceptible to sheet erosion. The eroding and transporting power of sheet flow are function of a depth and velocity of runoff for a given size, shape and density of soil particle or aggregate.
    b) Rill & Ravine erosion: It is the removal of soil by water from small but well-defined channel or streamlets where there is a concentration of overland flow. There is no sharp line of demarcation where sheet erosion ends and rill erosion begins. Rills are small enough to be easily removed by normal tillage operation. Detachability and transportability are both greater in rill erosion than in sheet erosion because of high velocities. Rill erosion is the most serious where intense storm occurs on soil having high runoff producing characteristics and loose, shallow topsoil.

c) Gully erosion: It produces channels larger than rills. These channels carry water during and immediately after rains and as distinguished from rills, gullies cannot be obliterated by tillage. Thus gully erosion is an advanced stage of sheet erosion. The rate of gully erosion depends primarily on the runoff producing characteristics of water shed, the drainage area, soil characteristics, the alignment, size and shape of the gully, and the slope in the channel. A gully develops by processes that may take place either simultaneously or during different periods of its growth. These processes are: (1) Water fall erosion at the gully head, (2) Channel erosion caused by the water flowing through the gully or by rain-drop splash, (3) Alternate freezing and thawing of exposed soil banks, and (4) Slides or mass movement of soil in the gully.

2. Wind erosion: Soil erosion by wind is common in dry (arid) regions where soil is chiefly sandy and the vegetation is very poor or even absent. As in water erosion, wind erosion also is triggered by the destruction of natural vegetation cover of land by over felling and over grazing. Once, the topsoil is laid bare to the fury of strong gales it gets blown off in the form of dust storm and sand storm. The high velocity winds blow away the soil particles. Depending upon the whole mechanism of the soil removal, this may be of the following types:

(a) Saltation: In such arid regions where rainfall is low, drainage is poor and high temperatures prevail, water evaporates quickly leaving behind the salts. Salt accumulation occurs mainly in lowlands around the oceans. The major portion of such salty soil is carried by wind in the form of small leaps, which is caused by direct pressure of wind on small particles of soil.

(b) Suspension: The wind throws away smallest soil particles into air, which move as fine dust with the wind. By this way soils are transported to fairly long distances.

(c) Surface creep: The heavier particles of soil that are not easily thrown up by wind, are simply pushed or spread along the surface by wind.

3. Landslides or Slip erosion: The hydraulic pressure caused by heavy rains increases the weight of the rocks at cliffs, which come under the gravitational force and finally slip or fall off. Sometimes entire hillock may slide down. In this type of erosion, water and gravity act together.

4. **Stream bank erosion:** The rivers during floods splash their water against the banks and thus cuts through them. Particularly at curves, water strikes with great speed and the bank caves in alongside. This type of erosion is also known as Riparian erosion.

3	Water erosion: Forms of water erosion

3.0 Water Erosion: It is the removal of soil from the land surface by flowing water. Water erosion is due to the dispersive action and transporting power of water-water as it descends in the rain and leaves the land in the form of runoff. Rainfall is the chief detaching agent in water erosion.

Water erosion is a complex three-step natural phenomenon which involves *detachment*, *transport*, and *deposition* of soil particles. The process of water erosion begins with discrete raindrops impacting the soil surface and detaching soil particles followed by transport. Detachment of soil releases fine soil particles which form surface seals. These seals plug the open-ended and water-conducting soil pores, reduce water infiltration, and cause runoff. At the microscale level, a single raindrop initiates the whole process of erosion by weakening and dislodging an aggregate which eventually leads to large-scale soil erosion under intense rainstorms. The three processes of erosion act in sequence (Table 3.1).

The first two processes involving dispersion and removal of soil define the amount of soil that is eroded, and the last process (deposition) determines the distribution of the eroded material along the landscape. If there were no erosion, there would be no deposition. Thus, detachment and entrainment of soil particles are the primary processes of soil erosion, and, like deposition, occur at any point of soil. When erosion starts from the point of raindrop impact, some of the particles in runoff are deposited at short distances while others are carried over long distances often reaching large bodies of flowing water.

Table 3.1 Role of the three main processes of water erosion

Detachment	Transport	Deposition
▪ Soil detachment occurs after the soil adsorbs raindrops and pores are filled with water. ▪ Raindrops loosen up and break down aggregates. ▪ Weak aggregates are broken apart first. ▪ Detached fine particles move easily with surface runoff. ▪ When dry, detached soil particles form crusts of low permeability. ▪ Detachment rate decreases with increase in surface vegetative cover.	▪ Detached soil particles are transported in runoff. ▪ Smaller particles (e.g., clay) are more readily removed than larger (e.g., sand) particles. ▪ The systematic removal of fine particles leaves coarser particles behind. ▪ The selective removal modifies the textural and structural properties of the original soil. ▪ Eroded soils often have coarse-textured surface with exposed subsoil horizons.	▪ Transported particles deposit in low landscape positions. ▪ Most of the eroded soil material is deposited at the downslope end of the fields. ▪ Placing the deposited material back to its origin can be costly. ▪ Runoff sediment transported off-site can reach downstream water bodies and cause pollution. ▪ Runoff sediment is deposited in deltas along streams. ▪ Texture of eroded material is different

	▪ Amount of soil transported depends on the soil roughness. ▪ Presence of surface residues and growing vegetation slows runoff.	from the original material because of the selective transport process.

3.1 Types of Water Erosion

Water erosion is caused by water – water that comes in rain and runs off the land as overland flow or streamfl ow. At the initial stage, soil particles are detached from aggregates by the impact of falling raindrops or fl owing water, which is followed by transport of the detached particles by runoff water. Runoff water laden with suspended particles also detaches more soil particles in its way across the surface.

Soil erosion is a process of soil loss, particularly from the surface, but sometimes a large mass of soil may be lost, as in landslides and riverbank erosion. Water erosion can be classified into sheet erosion, internal erosion, and channel erosion. Channel erosion was further divided into rill erosion, gully erosion, and stream erosion. However, the following four types of water erosion are generally recognized: splash erosion, sheet erosion, rill erosion, and gully erosion. Splash and sheet erosion are sometimes called interrill erosion.

3.1.1 Splash Erosion

At the start of a rain event, falling raindrops beat the soil aggregates, break them, and detach soil particles. These particles clog the large soil pores and, thus, reduce the infiltration capacity of the soil. Water cannot enter the soil, and soon a thin film of water covers the ground. Further, raindrops beat the water and splash the suspended soil particles away. Soil particles are transported to some distance by the splashing. The splashed particles can rise as high 60 cm above the ground and move up to 1.5 m from the point of impact. Processes of splash erosion involve raindrop impact, splash of soil particles, and formation of craters. Actually, splash erosion (Fig. 29.1) is the beginning of other types of soil erosion, particularly sheet erosion .

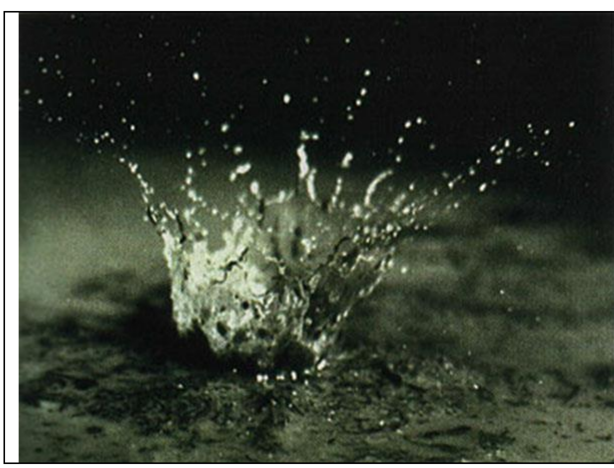

Fig. 29.1 Splash erosion

3.1.2 Sheet Erosion

When a thin layer of soil is removed by raindrop impact and shallow surface flow from the whole slope, it is called sheet erosion. It removes the finest fertile topsoil with plenty of nutrients and organic matter. It is the most dangerous type of soil erosion because it occurs gradually and almost silently leaving little or no signs of soil removal.

Sheet erosion involves the removal of a more or less uniform layer of soil over the whole slope of the land. Soil particles are detached primarily by raindrops and secondarily by frost, hooves of farm animals, tillage, and mechanical action of farm machines. Detached particles are transported by runoff water as overland flow. Sheet erosion is more uniform and gradual, as the surface becomes smoother. However, water may still accumulate even on the smoothest slope. The intensity of accumulation of runoff water depends on the height of the water stream, the coarseness of the surface, vegetation, or crop distribution. Sheet erosion removes deeper layer of soil gradually, if allowed to proceed unhindered and the subsoil is exposed over a large area. The subsoil is usually of different texture and color and is more compacted. However, slopes are often not so uniform over the whole area, and water accumulates in tiny channels, so that the surface is crisscrossed by discontinuous rillets. It is then known as the interrill erosion. In addition to soil particles, sheet erosion removes

(i) organic residues accumulated on the surface soil and
(ii) soluble and easily dissoluble matter, matter made soluble by weak acids in rainwater.

Sheet erosion represents microerosion, that is, the eroding and washing of the soil to produce small- scale forms which may encompass raindrop erosion, laminar erosion, rillet erosion, and layer erosion. The first phase of sheet erosion, specific with regard to form, is soil removal by raindrop action – raindrop erosion. In raindrop erosion, the surface is acted upon selectively so that small holes, micropyramids, and other forms occur, raindrop erosion thus becoming a part of pedestal erosion, pinnacle erosion, etc.

The second subtype in sheet erosion is laminar erosion. It occurs in any flow of water on an inclined soil surface where the kinetic energy of the water is small and only the finest soil particles are consequently washed away in a strongly selective manner. By virtue of the accumulation of sheet runoff water, rill erosion develops, causing small rills with the dimensions of a few centimeters diameter in cross section, and with a depth not exceeding that of the arable layer.

The rillets that develop in rows and furrows, with the effect of increasing their dimensions and conspicuousness, are removed during cultivation. In this form of erosion, soil and particles displaced by water may be intensively separated and sorted. In layer erosion, the soil is washed away neither in laminae nor in rillets, but in a layer up to several meters wide and 10–25 cm deep from a tilled surface, that is, in apparent strips from which the topsoil has been entirely removed.

3.1.3 Rill Erosion

When rainfall exceeds the rate of infiltration, water accumulates on the surface, and if the land is sloping, it moves along the slope. On gently sloping lands, with standing crops or in fields that

have been recently tilled, moving water concentrates along tiny channels called rills. Rills are less than 30 cm deep. The cutting action of flowing water detaches soil particles, and runoff water carries them away. The amount of soil loss may be high, but the small channels do not usually interfere with tillage implements. The rills may be leveled by normal tillage operations. Rill erosion is often the initial stage of gully erosion.

Rill erosion is largely caused as a result of large amounts of material that are released and transported for variable distances in concentrated areas. On the other hand, the flow of water over the surface has a smaller effect on soil detachment, but a larger transportation effect. Yet flowing water, especially on tilled land, can become the agent of transport of particles loosened mechanically, chemically, or by means other than the water flow itself, and therefore it is a phenomenon of great importance from the point of view of total soil losses.

Water concentrates in places over the field due to reduction in infiltration, increase in precipitation, and surface roughness of the land. Water concentrates along tillage lines, rows of crops, impedance by exposed roots, around clods, etc. and from shallow and narrow channels known as rills. As this gathering of water proceeds, the total amount of water remaining the same, the depth of the water increases, together with the velocity, kinetic energy, and detaching as well as carrying capacity of the water. At high precipitation intensities, there is greater clogging of pores, and the proportion of precipitation water making up the surface flow and the numbers of particles separated from the soil by raindrops both increase.

Greater predominance of rill erosion may be found on steeper slopes with impermeable soil material consisting of younger sediments which are susceptible to erosion. As is seen usually, rill erosion prevails and affects the whole length of the slope, which means that precipitation water, as soon as it reaches the soil, flows away through the dense network of rills, virtually cutting the slope into thin plates. Occurrence of splash erosion or sheet erosion is not seen, but there was some erosion of these forms too. Similar phenomena occur on steep slopes, even on impermeable loamy clay material. On impermeable or still heavier and more resistant material, rill erosion forms ridges which are separated by sharply cut rillets and gullies.

The rillets are occasionally so narrow that they resemble cracks, and it could be termed crack erosion. On steep slopes composed of material of varying resistance, vertical openings are formed, and these soon develop into tunnel erosion or hollow erosion, separating the washed forms into isolated pipes, etc. Where the material is more homogeneous and the incline less steep, rilling prevails. If the material is more coarse grained and less resistant, flowing water carries the soil along rapidly and creates triangular or trough-shaped forms with respect to the cross section of the channel. In such cases, the lengths of the rills are greater, but the interrill lamellae are thinner, and the edges sharper.

The more coarsely grained and more permeable the material, the less pronounced is the channeling, until finally the rills are widely shaped, and resemble more the form of moderately undulating depressions, even on very steep parts of the eroded slope. On permeable, coarse-grained, non-resistant fluvioglacial deposits, on the other hand, shallow, rapidly growing rills develop with an immense production of silt. Here, the action of fl owing water is the predominant force. These forms are transitional toward gully erosion. Rill erosion usually begins

to appear in the lower part of the slope. This is true especially when the source of the water is thawing snow or precipitation of low intensity. As soon as the intensity of the rainfall increases, the intensity and velocity of surface runoff both increase also, and consequently the proportion of the total erosion due to rills becomes greater, depending on the permeability of the soil.

3.1.4 Gully Erosion

Gullies are large channels deeper than 30 cm. Gullies develop when large quantities of water accumulate and run through a single channel with high speed in relatively steep slopes (Fig. 29.2). Gullies may also develop by the gradual deepening of rills. There are two types of gullies: ephemeral and permanent. Ephemeral gullies form shallow channels that can be readily corrected by routine tillage operations. On the other hand, permanent gullies are very large and cannot be smoothed by regular tillage. Gullies of various size and form develop by the gradual deepening of rills. A number of forms may be distinguished in gully erosion. The first form includes gully with a depth between 30 cm and 2–3 m. In this form, typical wash prevails with a marked backward or retrograde erosion and vertical or depth erosion. Gullies have larger dimensions and their development is more complicated.

Besides retrograde and vertical erosion, lateral erosion also appears here, together with accessory landslide, soil flow, and other phenomena. Gullies may grow into gorges and canyons in high altitudes and very steep slopes. Gullies may be flat, narrow, broad, and round. Flat forms occur mostly on shallow soil or in connection with a specific lithic structure of the slope. In this form, characterized by a broad V-section, lateral erosion prevails over vertical erosion. Narrow, acute forms are created with a narrow V-section, the breadth of the gully usually being equal to its depth or smaller. Broad gullies have a wide bottom and are U shaped. Here, lateral erosion prevails over depth erosion. Active gullies maintain steep or even perpendicular sides. It happens frequently that recent forms replace older forms so that their origin and age cannot be assessed from superficial observation. The main feature of gully erosion is the volume and velocity of water at the lowest level. The energy of flowing water increases its cutting and smashing power and often results in bank erosion.

Fig. 29.2 Gully Erosion

3.1.5 Riverbank/Stream Bank Erosion

Stream/riverbank erosion occurs due to bank scour and mass failure. The direct removal of bank materials by the physical action of flowing water is called bank scour. It is often dominant in smaller streams and the upper reaches of larger streams and rivers. Mass failure occurs when

large chunks of bank material become unstable and topple into the stream or river. Riverbank erosion can be accelerated by lowering streambed, inundation of bank soils followed by rapid drops in water flow, saturation of banks from off-stream sources, removal of protective vegetation from stream banks, poor drainage, readily erodible material within the bank profile, wave action generated by boats, excessive sand and gravel extraction, and intense rainfall.

4	Gully classification and control measures

4.0 Gully erosion: It is an advance stage of rill erosion as rill erosion is the advanced stage of sheet erosion. It is the most spectacular form of erosion. Any concentration of surface runoff is a potential source of gully erosion. The Soil Conservation Society of America defines a gully as "a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains. It may be dendritic or branching or it may be linear, rather long, narrow and of uniform width". In India, the rate of soil erosion from gullies is 33 t/ha/yr in ravine regions (Shekinah and Saraswathy, 2005). The distinction between ravine, gully and rills is that of size. A gully is too large to be filled by normal tillage practices. A ravine is a deep narrow gorge. It is larger than a gully and is usually worn down by running water. It is estimated that about 4 million ha of land in India are affected by gully erosion (Michael and Ojha, 2012).

4.1 Development of Gullies

The main processes in the development of gullies are waterfall erosion and channel erosion. These two erosions are commonly found in the same gully. The extension of the gully head is usually by waterfall erosion; while the scouring of bottom and sides which enlarges the depth and width of gullies is by channel erosion. Gullies usually start with channel erosion. When an overfall develops at the head of the gully, the gully continues to develop by waterfall erosion. The waterfall erosion at gully head and advancement of the gully towards the upper edge of the watershed is shown in Fig. 7.1.

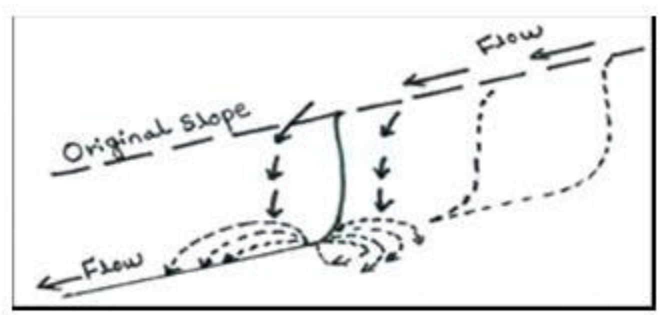

Fig. 7.1. Waterfall erosion at gully head.

The gully development is recognized in four stages:

Formation Stage: Scouring of top soil in the direction of general slope occurs as the runoff water concentrates. It normally proceeds slowly where the top soil is fairly resistant to erosion.

Development Stage: Causes upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon of soil, and the parent materials are removed rapidly as water flows.

Healing Stage: Vegetation starts growing in the gully.

Stabilization Stage: Gully reaches a stable gradient, gully walls attain a stable slope and sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new topsoil.

4.2 Classification of Gullies

Gullies can be classified based on three factors viz. their size, shape (cross section) and formation of branches or continuation. The detailed classification is discussed below.

4.2.1 Based on Size (depth and drainage area)

Gully classification based on the size is presented in Table 4.1.

Table 4.1. Gully classification based on size

Classification	Depth (m)	Drainage area (ha)
Small	< 1	< 2
Medium	1 to 5	2 to 20
Large	> 5	> 20

4.2.2 Based on Shape

The classification of gullies based on shape is shown in Fig 4.2.

U-Shaped: These are formed where both the topsoil and subsoil have the same resistance against erosion. Because the subsoil is eroded as easily as the topsoil, nearly vertical walls are developed on each side of the gully.

V-Shaped: These gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common form of gully.

Trapezoidal: These gullies are formed where the gully bottom is made of more resistant material than the topsoil. Below the bottom of gully, the subsoil layer has much more resistance to get eroded and thus the development of further depth of gully is restricted.

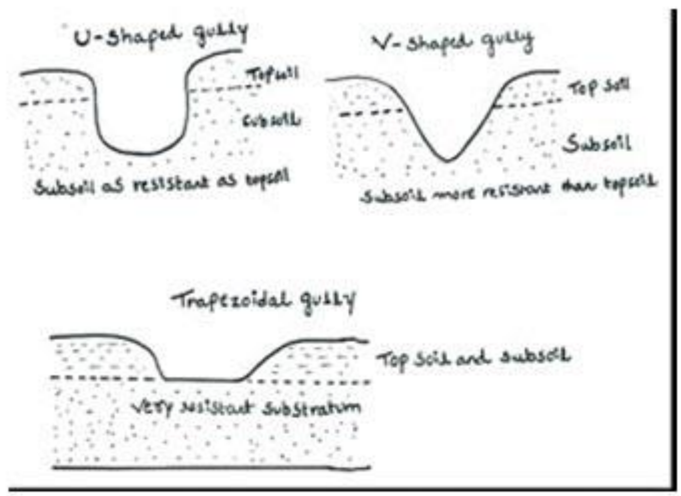

Fig. 4.2. Gully classes based on the shape of gully cross-section.

4.2.3 Based on the Formation of Branches or Continuation

Continuous Gullies: These gullies consist of many branches. A continuous gully has a main gully channel and many mature or immature branch gullies. A gully network is made up of many continuous gullies. A multiple-gully system may be composed of several gully networks.

Discontinuous Gullies: These may develop on hillsides after landslides. They are also called independent gullies. At the beginning of its development, a discontinuous gully does not have a distinct junction with the main gully or stream channel. Flowing water in a discontinuous gully spreads over a nearly flat area. After some time, it reaches the main gully channel or stream. Independent gullies may be scattered between the branches of a continuous gully, or they may occupy a whole area without there being any continuous gullies.

4.3 Principles of Gully Control

Generally, gullies are formed by an increase in surface runoff. Therefore, minimizing surface runoff is essential in gully control. The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, the watershed area, soil characteristics, size-shape and slope of gully etc. Watersheds deteriorate because of misuse of the land (man made changes), short intensive rainstorms, prolonged rains of moderate intensity, and rapid snow melts. The precipitation factors which turn into high runoff, develop flooding and form gullies. In gully control, the following three methods should be applied according to the order given:

- Improvement of gully catchments to reduce and regulate the runoff rates (peak flows).
- Diversion of surface water above the gully area.
- Stabilization of gullies by structural measures and accompanying re-vegetation.

When the first and/or second methods are applied in some regions of the countries with temperate climates, small or incipient gullies may be stabilized without having to use the third method. On the other hand, in tropical and subtropical countries which have heavy rains (monsoons, typhoons, tropical cyclones, etc.); all three methods have to be applied for successful gully control.

4.4 Gully Control Measures

Preventing the formation of gully is much easier than controlling it once it has formed. One of the major steps in a gully control programme is to plan the control of runoff from the drainage area. The various methods employed for controlling runoff may be considered in the following order:

- **Retention of Runoff on the Drainage Area:** It is possible through good crop management and applicable conservation practices such as contouring, strip cropping, bunding, terracing etc. Where contour bunds are used, runoff is greatly reduced. On cultivated areas, small and medium sized gullies can also be reclaimed by placing a series of earthfills across the gully.
- **Diversion of Runoff Around the Gullied Area:** The most effective control of gullies is by complete elimination of runoff from the gullied area. This can be obtained by diverting runoff from the gully, causing it to flow at a non- erosive velocity to a suitable outlet. Terraces and diversion ditches are generally used for diverting runoff from its natural outlet. Terraces are very effective in the control of small gullies on cultivated fields or even medium size shallow gullies. If the slope above a gully is too steep for terracing, or if the drainage area is pasture or woodland, diversion ditches may be used to keep the runoff out of the gully.
- **Conveyance of Runoff through the Gully:** If it is not possible to either retain or divert the runoff, then runoff must be conveyed through the gully itself. This is possible only if vegetation can be established in the gullies, or if soil conservation structures are built at critical points to give primary control.

4.5 Classification of Gully Control Measures or Structures

Basically gully control structures are used to reduce soil erosion, control sedimentation, and harvesting water. Gully control measures are mainly of two types.

4.5.1 Biological or Vegetative Measures

4.5.1.1 Anti-Erosion Crops

These crops stabilize gully. Crops produced provide supplementary income.

4.5.1.2 Changing Gully into Grassed Waterway

Small and medium size gullies can be converted into grassed waterways. In practice, gully is shaped and suitable species of grasses are grown. Channel cross-section should be broad and flat, to keep water spread uniform over a wide area.

4.5.1.3 Sod Flumes

It may be successfully used to control overfall in gullies with head < 3 m and area <10 ha. The design of sod flume is shown in Fig 4.3. It serves the purpose of preventing further waterfall erosion by providing a protected surface over which the runoff may flow into the gully. Slope varies with the soil type, size of watershed, height of overfall and type of sod used. 4:1 is the steepest slope considered for its design. To maintain a non-erosive velocity, flume should be wide enough. The maximum depth of flow over the flume should not exceed 30 cm.

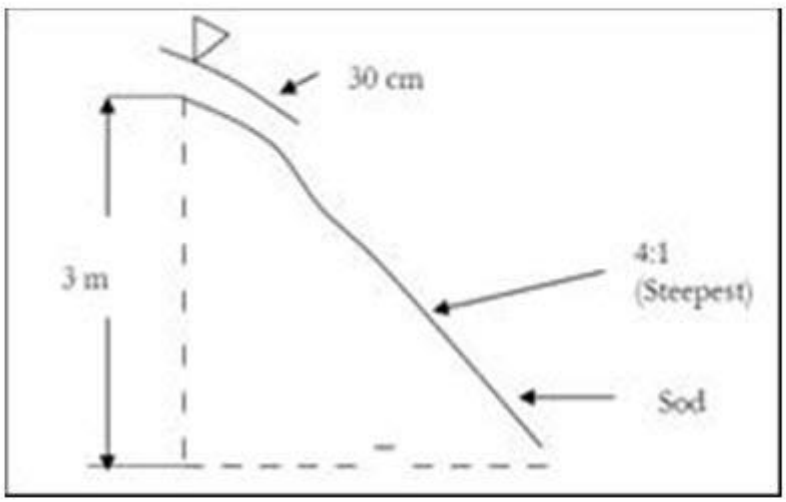

Fig. 4.3. Sod flume.

4.5.1.4 Sod Strip Checks

These checks are best adapted to small gullies with small to medium sized watersheds. These checks cannot be used in gullies with very steep grades. Strips are laid across gully channel (Fig. 4.4). Strips should have a minimum width of 30 cm and should extend up to gully sides at least 15 cm. Strip spacing usually varies from 1.5 to 2.0 m.

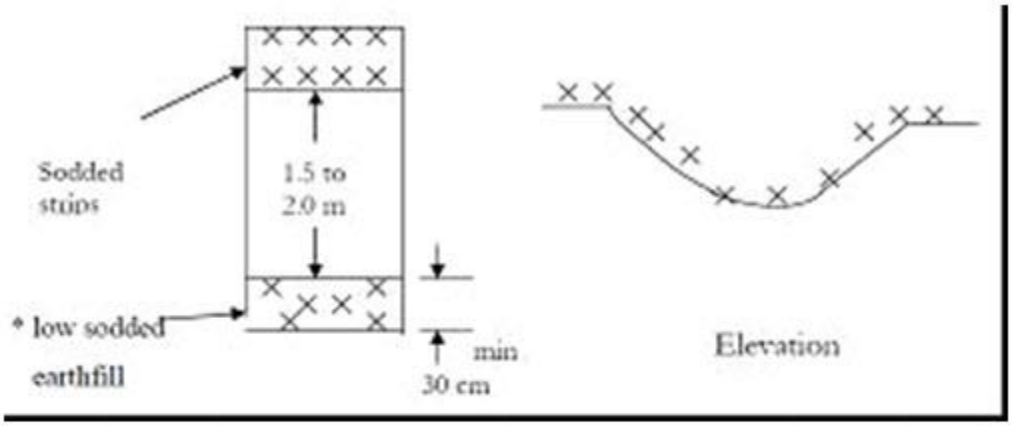

Fig. 4.4A. Sod strip checks.

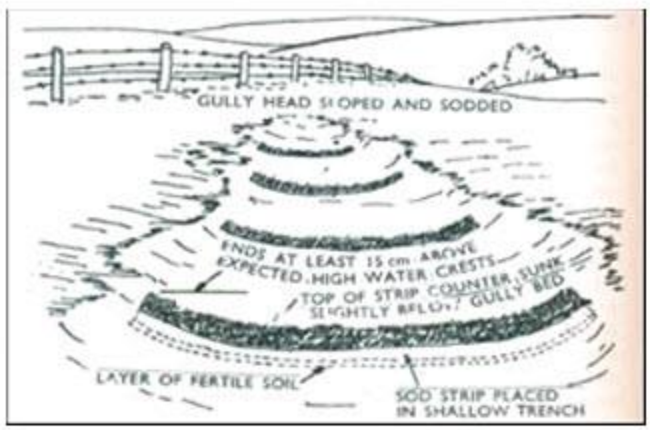

Fig. 4.4B. A series of sod-strip checks in a small gully.

4.5.1.5 Low Sodded Earthfills

These are used as substitutes for temporary gully controlled structures in small and medium sized gullies. Already growing sods are cut along with soil mass and combined together to form earth fill dams (Fig. 4.5). They are constructed with a maximum height of 45 cm, upstream (u/s) side slope of 3:1 and downstream (d/S) side slope of 4:1.

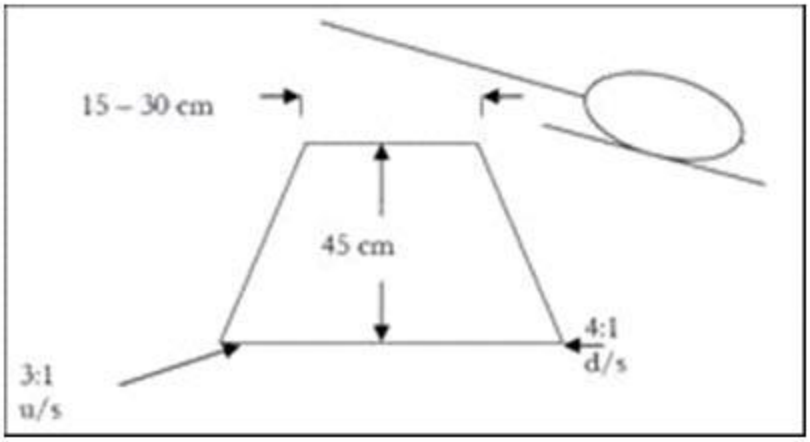

Fig. 4.5 Low sodded earthfills.

4.5.1.6 Trees, Shrubs etc.

Trees, shrubs etc. are used to stabilize severely eroded gullied area. Generally gullied area is fenced and trees are grown. A plant spacing of 1 × 1 m, 1.2 × 1.2 m or a maximum of 2 × 2 m should be maintained.

4.5.2 Engineering Measures (Temporary and Permanent)

4.5.2.1 Temporary Gully Control Structures (TGCS)

TGCS have a life span of 3 to 8 years and they are pretty effective where the amount of runoff is not too large. These are made of locally available materials. Basic purposes they serve are to retain more water as well as soil for proper plant growth and prevent channel erosion until sufficient vegetation is established on the upstream side of the gully. TGCS are of many types:

- Woven wire check dams
- Brush dams
- Loose rock dams
- Plan or slab dams
- Log check dams
- Boulder check dams

4.5.2.2 Permanent Gully Control Structures (PGCS)

If the erosion control programmer requires bigger structure, then PGCS are used. They include:

- Drop spillway
- Drop-inlet spillway
- Chute spillway
- Permanent earthen check dams

4.6 Design Criteria of TGCS

- The overall height of a temporary check shouldn't ordinarily be more than 75 cm. An effective height of about 30 cm is usually considered sufficient. Also, sufficient freeboard is necessary.
- Life of the check dams under ordinary conditions should be in between 3 to 8 years.
- Spillway capacity of check dams is generally designed to handle peak runoff that may be expected once in 5 to 10 year return period.
- Since the purpose of check dams in gully control is to eliminate grade in the channel, check dams theoretically should be spaced in such a way that the crest elevation of one will be same as the bottom elevation of the adjacent dam up-stream.
- As an integral part of most of the checks dams, an apron or platform of sufficient length and width must be provided at the down-stream end to catch the water falling over the top and to conduct it safely without scouring.

4.6.1 Woven Wire Check Dams

Woven-wire check dams are small barriers which are usually constructed to hold fine material in the gully (Fig. 4.6).

General:

- Used in gullies of moderate slopes (not more than 10 percent) and small drainage areas that do not have flood flows which carry rocks and boulders.
- Help in the establishment of vegetation for permanent control of erosion.
- Dam is built in half-moon shape with the open end up-stream.
- The amount of curvature is arbitrary: but an off-set equal to 1/6th of the width of gully at the dam site is optimum.

Construction:

- To construct a woven-wire dam, a row of posts is set along the curve of the proposed dam at about 1.2 m intervals and 60-90 cm deep.
- Heavy gauge woven wire is placed against the post with the lower part set in a trench (15-20 cm deep), and 25-30 cm projected above the ground surface along the spillway width.
- Rock, brush or sod may be placed approximately up to a length of 1.2 m to form the apron.
- For sealing the structure, straw, fine brush or similar material should be placed against the wire on the upstream side upto the height of spillway.

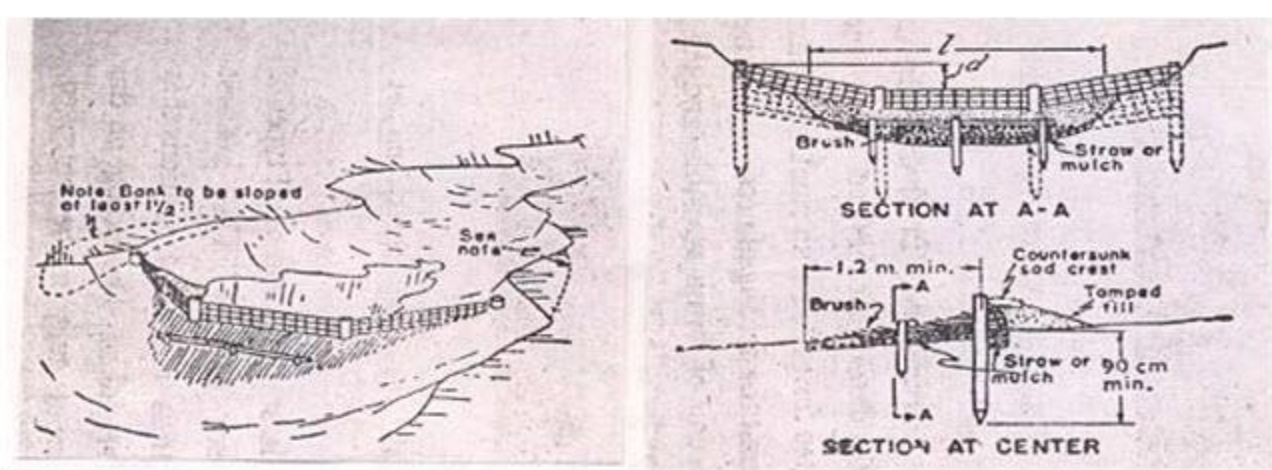

Fig. 4.6. Woven wire check dams.

4.6.2 Brush Dams

General:

- Cheap and easy to build, but least stable of all types of check dams.
- Best suited for gullies with small drainage area.
- Center of the dam is kept lower than the ends to allow water to flow over the dam rather than around it (Fig. 4.7).

Construction:

- For a distance of 3-4.5 m along the site of the structure, sides and bottom of the gully are covered with thin layer of straw or similar fine mulch.
- Brushes are then packed closely together over the mulch to about one half of the proposed height of dam.
- Several rows of stakes are then driven crosswise in the gully, with rows 60 cm apart, and stakes 30-60 cm apart in the rows.
- Heavy galvanized wire is used to fasten the stakes in a row, as well as to firmly compress the brushes in places.
- Sometimes large stones are also placed on top of brush to keep it compressed and in close contact with the bottom of the gully.
- Major weakness is the difficulty of preventing the leaks and constant attention is required to plug openings of appropriate size with straw as they develop.

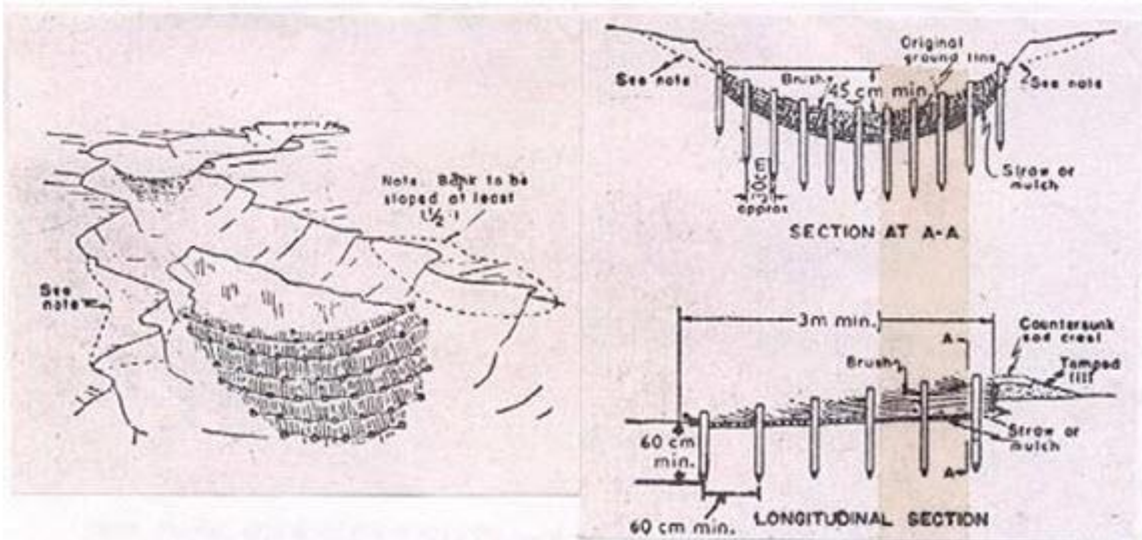

Fig. 4.7. Brush dam.

4.6.3 Loose Rock Dams

Loose rock dams made of relatively small rocks are placed across the gully (Fig. 4.8). The main objectives for these dams are to control channel erosion along the gully bed, and to stop waterfall erosion by stabilizing gully heads. Loose stone check dams are used to stabilize the incipient and small gullies and the branch gullies of a continuous gully or gully network. The length of the gully channel is not more than 100 m and the gully catchment area is 2 ha or less. These dams can be used in all regions.

General:

- Suitable for gullies with small to medium size drainage area.
- Used in areas where stones or rocks of appreciable size and suitable quality are available.
- Flat stones are the best choice for dam making.
- Stones can be laid in such a way that the entire structure is keyed together.
- If round or irregular shaped stones are used, structure is generally encased in woven-wire so as to prevent outside stones from being washed away.
- If the rocks are small, they should be enclosed in a cage of woven-wire.

Construction:

- A trench is made across the gully to a depth of about 30 cm. This forms the base of the dam on which the stones are laid in rows and are brought to the required height.

- The center of the dam is kept lower than the sides to form spillway.
- To serve as an apron, several large flat rocks may be countersunk below the spillway, extending about 1 m down-stream from the base of the dam.

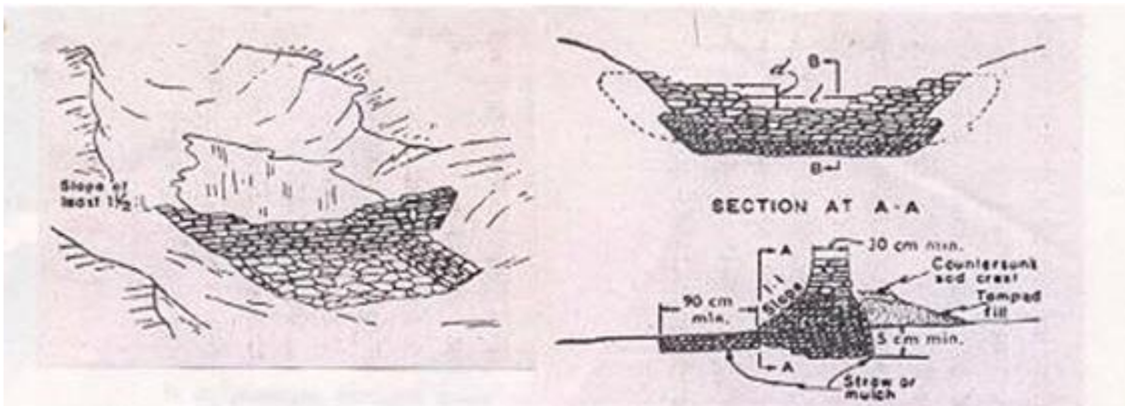

Fig. 4.8. Loose rock dam.

4.6.4 Plank or Slab Dam

General:

- These dams are suitable in areas where timber is plentiful, and dam can be constructed with much less labor as compared to other types of temporary structures.
- These dams can generally be used in gullies with larger drainage area.

Construction:

- The planks are placed across the gully to form the dam. If the planks are not close fitting, straw or grass may be used for sealing purposes.
- A suitable opening for the spillway notch is made over the headwall. On the up-stream face, a well tempered earth fill is made.
- On the down-stream, the apron may be made of loose rock, brush, sod or planks.

4.6.5 Log Check Dam

They are similar to plank or slab dams. Logs and posts used for the construction are placed across the gully. They can also be built of planks, heavy boards, slabs, poles or old railroad ties. The main objectives of log check dams are to hold fine and coarse material carried by flowing water in the gully, and to stabilize gully heads. They are used to stabilize incipient, small and

branch gullies generally not longer than 100 m and with catchment areas of less than two hectares. The maximum height of the dam is 1.5 m from the ground level. Both, its downstream and upstream face inclination are 25 percent backwards. The spillway is rectangular in shape. In general, the length and depth of spillway are one to two meters and 0.5 to 0.6 m respectively (Fig. 4.9).

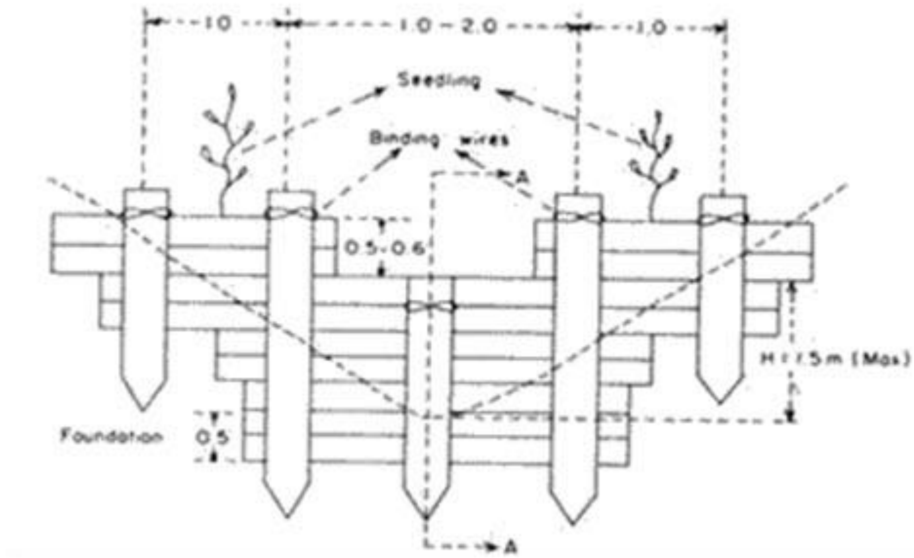

Fig. 4.9A. Front view of the first log check dam.

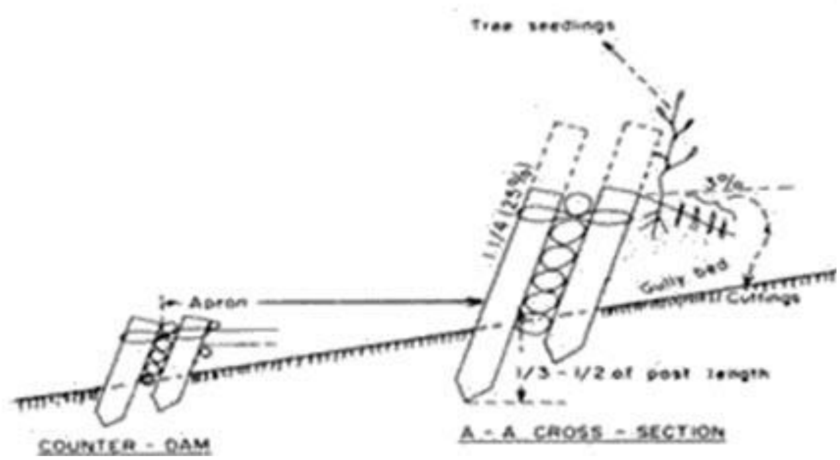

Fig. 4.9B. A-A cross-section of the first log check dam and counter dam.

4.6.6 Boulder Check Dams

Boulder check dams placed across the gully are used mainly to control channel erosion and to stabilize gully heads. In a gully system or multiple-gully system all the main gully channels of continuous gullies (each continuous gully has a catchment area of 20 ha or less and its length is

about 900 m) can be stabilized by boulder check dams. These dams can be used in all regions. The maximum total height of the dam is 2 m. Foundation depth must be at least half of the effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m (average 0.85 m), and the inclination of its downstream face is 30 percent (1:0.3 ratio); the thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical. If the above-mentioned dimensions are used, it is not necessary to test the stability of the dam against overturning, collapsing and sliding. The dimensions of the spillway (Fig. 4.10) should be computed according to the maximum discharge of the gully catchment area. The form of the spillway is generally trapezoidal.

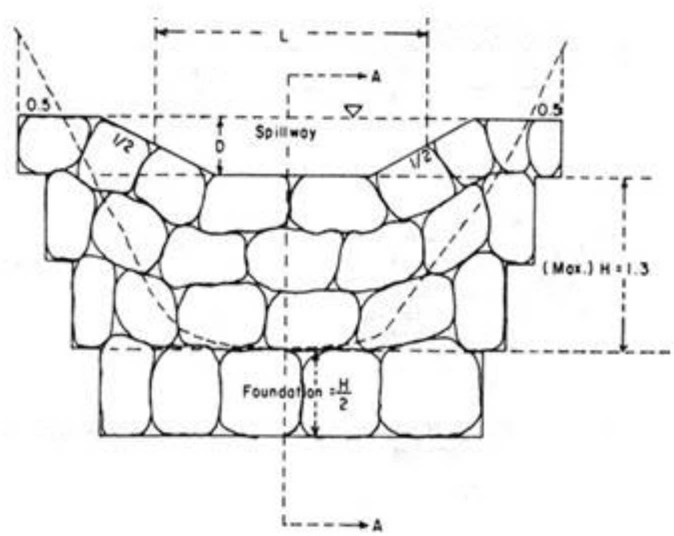

Fig. 4.10. Front view of the boulder check dam.

Problem 4.1: Design the notch dimensions of a wooden slab dam to carry a peak flow of 0·6 m^3/sec. The notch has rectangular opening. Width of gully channel is 2·5 m.

Solution

Q = 0·6 m^3/sec = 600 litres/sec

Length, L, of notch = width of gully channel

= 2·5 m = 250 cm

$Q = 0{\cdot}0171\ LH^{3/2}$

Substituting the values in the formula,

$600 = 0{\cdot}0171 \times 250 \times H^{3/2}$

H = 27·01 cm, say 27 cm

Assume a freeboard of 5 cm

Total depth of notch = 27 + 5 = 32 cm

The design dimensions of the notch are: length 2·5 m; total depth 32 cm.

05	Soil loss estimation by universal Loss Soil Equation.

5.0 Introduction

The Universal Soil Loss Equation (USLE), developed by Agricultural Research Service (ARS) scientists W. Wischmeier and D. Smith, has been the most widely accepted and utilized soil loss equation for over 30 years. Designed as a method to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. While it can estimate long - term annual soil loss and guide conservationists on proper cropping, management, and conservation practices, it cannot be applied to a specific year or a specific storm. The USLE is a mature technology and enhancements to it are limited due to its simple equation structure.

5.1 The Universal Soil Loss Equation (USLE)

The USLE developed in the USA is the most widely used empirical model worldwide for estimating soil loss (Wischmeier and Smith, 1965). Information from the USLE is used in planning and designing conservation practices. This model is not strictly based on hydraulic principles and soil erosion theory. It makes simplified assumptions in the processes of soil erosion. The USLE was specifically intended to predict soil loss from cultivated soils under specific characteristics. It has sometimes been used inappropriately and applied to soil and land use conditions different from those for which it was developed. It provides a long-term annual average estimate of soil loss from small plots or field segments with defined dimensions. The USLE was developed from measured data rather than using physically-based modeling approaches.

The limited consideration of all the complex and interactive factors and processes of soil erosion with the USLE limits its applicability to all conditions.

The USLE is, however, advantageous over sophisticated models because it is simple, easy to use, and does not require numerous input parameters or extensive data sets for prediction. The simplicity of the equation for its practical use has sacrificed accounting for all the details of soil erosion. Parameters are estimated from simple graphs and equations. Unlike process-based models, the USLE cannot simulate the following:

- Runoff, nutrient, and soil loss from watersheds or large catchment areas.
- Soil loss on an event or daily basis and variability of soil loss from storm to storm.
- Interrill, rill, gully, and streambank erosion separately.
- Processes of concentrated flow or flow channelization and sediment deposition.
- Detailed processes (e.g., detachment, transport, and deposition).

The average annual soil loss is estimated as:

$$A = R*K*LS*C*P$$

Where, A is average annual soil loss (Mg ha^{-1}), R is rainfall and runoff erosivity index for the location of interest, K is erodibility factor, LS is topographic factor, C is cover and management factor, and P is support practice factor. The early versions of USLE were exclusively solved using tables and figures (e.g. nomographs). The continued improvement has resulted in MUSLE and Revised USLE (RUSLE 1and 2).

- **Rainfall and Runoff Erosivity Index (EI)**

The EI is computed as the product of total storm energy (E, J/m^2) times the maximum 30-min intensity (I_{30}) of the rain (mm h^{-1}).

$EI = E \times I_{30}$

The USLE uses the annual EI which is computed by adding the EI values from individual storms that occurred during the year. According to Wischmeier and Smith (1978), the EI corresponds closely to the amount of soil loss from a field. The EI as used in the USLE over-estimates the EI for tropical regions with intensive rains. The USLE-computed EI is only valid for rain intensities $\leq$ 63.5mm h^{-1}. Modifications to EI have been proposed for tropical regions (Lal, 1976). The 30-minute intensity for a given storm and location is obtained from rain gauge charts recording the rainfall. Values of EI_{30} below 50 **(**mm h^{-1}**)** correspond to dry regions and those above 500 (mm h^{-1}) correspond to humid regions.

- **Rainfall Erosivity factor (R)**

The erosivity factor of rainfall (R) is a function of the falling raindrops and the rainfall intensity, Wischmeier and Smith (1958) found that the product of the kinetic energy (E, j/m^2) of the raindrop and the maximum intensity of rainfall over a duration of 30 minutes (I_{30}) of the rain (mm h^{-1}), in a storm, was the best estimator of soil loss. This product is known as EI value.

$$EI = E \times I_{30} \qquad (5.1)$$

The USLE uses the annual EI which is computed by adding the EI values from individual storms that occurred during the year. According to Wischmeier and Smith (1978), the EI corresponds closely to the amount of soil loss from a field. The EI as used in the USLE over-estimates the EI for tropical regions with intensive rains. The USLE-computed EI is only valid for rain intensities $\leq$ 63.5mm h⁻1. Modifications to EI have been proposed for tropical regions (Lal, 1976). The 30-minute intensity for a given storm and location is obtained from rain gauge charts recording the rainfall. Values of EI30 below 50 **(**mm h^{-1}**)** correspond to dry regions and those above 500 (mm h^{-1}) correspond to humid regions.

- **Soil Erodibility Factor (K)**

Soil erodibility refers to soil's susceptibility to erosion. It is affected by the inherent soil properties. The K values for the development of USLE were obtained by direct measurements of soil erosion from fallow and row-crop plots across a number of sites in the USA primarily under

simulated rainfall. The K values are now typically obtained from a nomograph or the following equation:

K = [0.00021 × M1.14 × (12 − a) + 3.25 × (b − 2) + 3.3 × 10−3(c − 3)] /100

M = (% silt + % very fine sand) × (100 − % clay)

Where, M is particle-size parameter, a is % of soil organic matter content, b is soil structure code (1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive), and c profile permeability (saturat d hydraulic conductivity) class [1 = rapid (150 mm h^{-1}); 2 = moderate to rapid (50–150 mm h^{-1}); 3 = moderate (12–50 mm h^{-1}); 4 = slow to moderate (5–15 mm h^{-1}); 5 = slow (1–5 mm h^{-1}); 6 = very slow (<1 mm h^{-1})]. The size of soil particles for very fine sand fraction ranges between 0.05 and 0.10 mm, for silt content between 0.002 and 0.05, and clay <0.002 mm. The soil organic matter content is computed as the product of percent organic C and value given in Table 5.1.

Table 5.1. K Factor Data (Organic Matter Content)

Textural Class	Average	Less than 2 %	More than 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	--	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	-	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

- **Topographic Factor (LS)**

The USLE computes the LS factor as a ratio of soil loss from a soil of interest to

that from a standard USLE plot of 22.1m in length with 9% slope as follows:

$LS = (Length/22.1)^m\ (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$

$m = 0.6\,(1 - \exp(-35.835 \times S))$

$\theta = \tan^{-1}(S/100)$

Where, S is field slope (%) and θ is field slope steepness in degrees.

Table 5.2. LS Factor Calculation

Slope Length ft (m)	Slope (%)	LS Factor
100 ft (31 m)	10	1.3800
	8	0.9964
	6	0.6742
	5	0.5362
	4	0.4004
	3	0.2965
	2	0.2008
	1	0.1290
	0	0.0693
200 ft (61 m)	10	1.9517
	8	1.4092
	6	0.9535
	5	0.7582
	4	0.5283
	3	0.3912
	2	0.2473
	1	0.1588
	0	0.0796
400 ft (122 m)	10	2.7602
	8	1.9928
	6	1.3484
	5	1.0723
	4	0.6971
	3	0.5162
	2	0.3044
	1	0.1955
	0	0.0915
800 ft (244 m)	10	3.9035
	8	2.8183
	6	1.9070
	5	1.5165
	4	0.9198
	3	0.6811
	2	0.3748
	1	0.2407
	0	0.1051

1600 ft (488 m)	10	5.5203
	8	3.9857
	6	2.6969
	5	2.1446
	4	1.2137
	3	0.8987
	2	0.4614
	1	0.2964
	0	0.1207
3200 ft (975 m)	10	7.8069
	8	5.6366
	6	3.8140
	5	3.0330
	4	1.6015
	3	1.1858
	2	0.5680
	1	0.3649
	0	0.1386

- **Cover-Management Factor (C)**

The C-factor is based on the concept that soil loss changes in response to the vegetative crop cover during the five crop stage periods: rough fallow, seedling, establishment, growing, and maturing crop, and residue or stubble. It is computed as the soil loss ratio from a field under a given crop stage period compared to the loss from a field under continuous and bare fallow conditions with up- and down-slope tillage (Wischmeier and Smith, 1978). Depending on the crop type and tillage method, the two sub-factors defining the C, are multiplied to compute the C-values. Estimates of C values for selected vegetation types are shown in Table 5.4. Detailed calculations of C values are presented by Wischmeier and Smith (1978).

- **Support Practice Factor (P)**

The P-factor refers to the practices that are used to control erosion. It is defined as the ratio of soil lost from a field with support practices to that lost from a field under up-and down-slope tillage without these practices. The P values vary from 0 to 1 where the highest values correspond to a bare without any support practices. Maintaining living and dead vegetative cover and practicing conservation tillage significantly reduces soil erosion. The combined use of various practices is more effective than a single practice for controlling erosion in highly erodible soils. In such a case, support practices (P) including contouring, contour strip-cropping, terracing, and grass waterways must be used. The P values are obtained from Tables 17.4 and 17.5.

In systems with various support practices, P values are calculated as follows:

$P = P_c \times P_s \times P_t$

where Pc is contouring factor for a given field slope, Ps is strip cropping factor, and Pt is terrace sedimentation factor (Table 17.5).

Table 5.3. "C" values for some tillage and cropping systems

Vegetation	Description	C values
Grain corn	Moldboard plow, no residues, plowed during:	
	– fall	0.40
	– spring	0.36
	Mulch tillage	0.24
	Chisel plow, >50% residue cover, spring plowing	0.20
	Ridge tillage	0.14
	No-till with 100% residue cover	0.05
Corn silage and beans	Moldboard plow, no residues, plowed during:	
	– fall	0.50
	– spring	0.45
	Mulch tillage	0.30
	Ridge tillage	0.17
	No-till with 100% residue cover	0.10
Cereals	Fall plowed	0.35
	Spring plowed	0.32
	Mulch tillage	0.21
	Ridge tillage	0.12
	No-till with 100% residue cover	0.08
Corn-soybean rotation	Moldboard plow, no residues, fall plowing	0.50
	Chisel plow, >50% residue cover, spring plowing	0.23
	No-till with 100% residue cover	0.05
Corn-soybean rotation	Moldboard plow, no residues, fall plowing	0.20
	Chisel plow, >50% residue cover, spring plowing	0.14
	No-till with 100% residue cover	0.05
Hay and pasture	Dense stand of sod-like grass	0.02
Forest	>90% canopy cover and 100% litter cover	0.001
Short and managed trees without understory vegetation (fruit trees)	At least 75% of canopy cover without litter cover	0.35
	At least 75% of canopy cover with about 30% litter cover	0.08

Table 5.4. P values for contouring and strip-cropping

Land slope (%)	Contouring		Strip cropping				
	P value	Maximum slope length (m)	P value			Strip width (m)	Maximum slope length (m)
			A	B	C		
1–2	0.60	122	0.3	0.45	0.60	40	243
3–5	0.50	91	0.25	0.38	0.50	30	182
6–8	0.50	61	0.25	0.38	0.50	30	122
9–12	0.60	36	0.30	0.45	0.60	24	74
13–16	0.70	24	0.35	0.52	0.70	24	49
17–20	0.80	18	0.40	0.60	0.80	18	36
20–25	0.9	15	0.45	0.68	0.90	15	30

Table 5.5. P values for combined support practices

Land slope (%)	Contour factor	Strip crop factor	Terrace factor		
			Terrace interval (m)	Closed outlets	Open outlets
1–2	0.60	0.30	33	0.5	0.7
3–8	0.50	0.25	33–44	0.6	0.8
9–12	0.60	0.30	43–54	0.7	0.8
13–16	0.70	0.35	55–68	0.8	0.9
17–20	0.80	0.40	69–60	0.9	0.9
21–25	0.90	0.45	90	1.0	1.0

Table 5.6. Management Strategies to Reduce Soil Losses

Factor	Management Strategies	Example
R	The R Factor for a field cannot be altered.	--
K	The K Factor for a field cannot be altered.	--
LS	Terraces may be constructed to reduce the slope length resulting in lower soil losses.	Terracing requires additional investment and will cause some inconvenience in farming. Investigate other soil conservation practices first.
C	The selection of crop types and tillage methods that result in the lowest possible C factor will result in less soil erosion.	Consider cropping systems that will provide maximum protection to the soil. Use minimum tillage systems where possible.
P	The selection of a support practice that has the lowest possible factor associated with it will result in lower	Use support practices such as cross slope farming that will cause sediment deposition close to the source.

	soil losses.	

5.2 Application of USLE

1. The USLE was developed as a working tool for soil erosion prediction and soil conservation and erosion control planning. It was developed for application on very small land areas e.g. single fields within a farm, and most of the quantification of the factors in the equation were developed from studies on small field plots.
2. Application of the USLE to the analysis of nonpoint source pollution has been increasing in recent years and in many cases may be used beyond its limitations. Better predictive tools are needed, particularly with respect to sediment delivery ratios, and models which consider the physical processes involved in erosion and sediment transport.
3. The USLE only predicts soil loss by sheet and rill erosion as a result of rainfall impact on soils. The movement of dislodged soil particles to streams is not modelled. In some applications of the USLE, this is covered by a sediment delivery ratio (S_d). The determination and use of sediment delivery ratios is subject to considerable controversy and misuse.

5.3 Limitations of USLE

1. The model applies only to sheet erosion since the source of energy is rain; so it never applies to linear or mass erosion and predicts the average soil loss.
2. The type of countryside: the model has been tested and verified in plain and hilly countries with 1-20% slopes, and excludes young mountains, especially slopes steeper than 40%, where runoff is a greater source of energy than rain and where there are significant mass movements of earth.
3. The type of rainfall: the relations between kinetic energy and rainfall intensity generally used in this model apply only to the American Great Plains, and not to mountainous regions although different sub-models can be developed for the index of rainfall erosivity, R.
4. The model applies only for average data over 20 years and is not valid for individual storms. A MUSLE model has been developed for estimating the sediment load produced by each storm, which takes into account not only rainfall erosivity but also the volume of runoff (Williams 1975).
5. Lastly, a major limitation of the model is that it neglects certain interactions between factors in order to distinguish more easily the individual effect of each factor. For example, it does not take into account the effect on erosion of slope combined with plant cover, or the effect of soil type along with the effect of slope.
6. The USLE does not calculate sediment deposition.

06	Soil loss measurement techniques.

Data on soil erosion and its controlling factors can be collected in the field or, for simulated conditions, in the laboratory. Whether field or laboratory studies are used depends on the objective. For realistic data on soil loss, field measurements are the most reliable, but because conditions vary in both time and space, it is often difficult to determine the chief causes of erosion or to understand the processes at work. Experiments designed to lead to explanation are best undertaken in the laboratory, where the effects of many factors can be controlled. Because of the artificiality of laboratory experiments, however, some confirmation of their results in the field is desirable.

6.1 Experimental design

Experiments are usually carried out to assess the influence of one or more factors on the rate of erosion. In a simple experiment to study the effect of slope steepness, it is assumed that all other factors likely to influence erosion are held constant. The study is carried out by repeating an experiment for different slope steepnesses. Decisions are necessary on the range of steepnesses, the specific steepnesses within the range and whether these should reflect some regular progression, e.g. 2°, 4°, 6°, rising in intervals of 2°, or 5°48c, 11°36c, 17°30c, rising in intervals of 0.1 sine values. The range can be selected to cover the most common slope steepnesses or extended to include extreme conditions. A decision is also needed on what levels to set for the factors being held constant, e.g. whether slope length should be 5 or 50m, or the rainfall intensity 20 or 200mmh-1.

Measurements are subject to error. Since no single measurement of soil loss can be considered as the absolutely correct value, it is virtually impossible to quantify errors.However; they can be assessed in respect of variability. This requires replicating the experiment several times to determine the mean value of soil loss – for example, for a given slope steepness in the above experiment – and the coefficient of variation of the data.

Generally, the variability in field measurement is higher than that in laboratory studies. The higher variability reflects the often highly localized variations in soil conditions, particularly infiltration and cohesion, that occur in the field, whereas in the laboratory, the soils are often processed by drying and sieving to give greater control over experimental conditions.

Systematic errors can be built into an experiment – for example, by starting the study of slope steepness effects on the gentlest slope, carrying out the rest of the study in a sequence of increasing slope steepness and following the same procedure for all the replications. In this way, the soil loss measured at a particular steepness is influenced consistently by the amount of erosion that has taken place on the next lowest slope steepness in the sequence. Remaking the soil surface between the separate runs of the experiment may not entirely eliminate this effect. Strictly, the order of the runs should be randomized but there is often a need to balance randomization with expediency and conduct some runs in sequence where it is very time-consuming to keep switching operating conditions.

In theory, no limits exist on the number of factors that may be incorporated in an experiment. In practice, the size and design of the experiment are usually limited by the amount of time and money available.

A problem faced in many experiments is how much data to collect. For instance, if the objective of a study is to measure total soil loss over a period of time, this can be achieved by collecting in bulk all the soil washed or blown from an area or by collecting the soil at regular shorter time intervals so as to obtain a total by summation of the loss in these time periods but also to learn about the pattern of loss over time. Restricting the measurement system to its bare essentials is usually cheaper and the data are generally easier to interpret. However, potentially useful information on whether most of the soil is eroded early or late in a storm is lost. This type of conflict is more apparent where the data are collected automatically. A decision then needs to be made on whether or not to analyse the shorter-period data.

There are no easy solutions to the problems of experimental design. Experiments should have clearly conceived objectives, define what needs to be measured and at what level of accuracy, and be set up in such a way that they can be easily repeated by others. Errors may arise due to different operators or the use of different equipment. In much soil erosion and conservation work, equipment is built by individual researchers and is not commercially available. As a result there is a multiplicity of methods and equipment and little standardization. The techniques described in this chapter are restricted to those in common use.

6.2 Field measurements and experiments

Field measurements may be classified into two groups: those designed to determine soil loss from relatively small sample areas or erosion plots, often as part of an experiment, and those designed to assess erosion over a larger area, such as a drainage basin.

6.2.1 Erosion plots

Bounded plots

Bounded plots are employed at permanent research or experimental stations to study the factors affecting erosion. Each plot is a physically isolated piece of land of known size, slope steepness, slope length and soil type from which both runoff and soil loss are monitored. The number of plots depends upon the purpose of the experiment but usually allows for at least two replicates. The standard plot is 22 m long and 1.8m wide, although other plot sizes are sometimes used. The plot edges are made of sheet metal, wood or any material that is stable, does not leak and is not liable to rust. The edges should extend 150–200mm above the soil surface and be embedded in the soil to a sufficient depth so as not to be shifted by alternate wetting-and-drying or freezing-and-thawing of the soil. At the downslope end is positioned a collecting trough or gutter, covered with a lid to prevent the direct entry of rainfall, from which sediment and runoff are channelled into collecting tanks. For large plots or where runoff volumes are very high, the overflow from a first collecting tank is passed through a divisor, which splits the flow into equal parts and passes one part, as a sample, into a second collecting tank (Fig. 6.1).

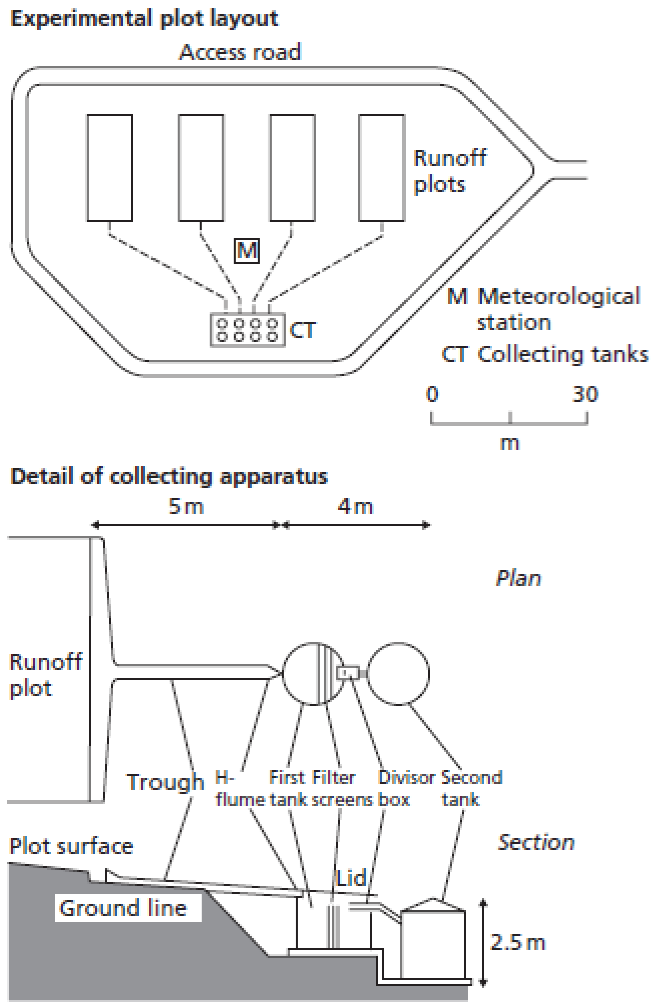

Fig. 6.1 Typical layout of erosion plots at a soil erosion and conservation research station (after Hudson 1965).

Although the bounded runoff plot gives probably the most reliable data on soil loss per unit area, there are several sources of error involved with its use (Hudson 1957). These include silting of the collecting trough and pipes leading to the tanks, inadequate covering of the troughs against rainfall and the maintenance of a constant level between the soil surface and the sill or lip of the trough. Considerable care is required if adequate data are to be obtained from runoff plots.

These ranges from the collecting tanks overflowing during extreme events, the tanks floating out of saturated ground, runoff entering the top of the plots, the taps in the collecting tanks being left open, to damage from termites, spiders and baboons! Other problems are that runoff may collect along the boundaries of the plot and form rills which would not otherwise develop, and that the plot is a partially closed system, being cut off from the input of sediment and water from upslope. The data obtained give a measure of soil loss from the entire plot that may be reasonably realistic of losses from fields under

similar conditions. The data do not give any indication of the redistribution of soil within a field or along a slope.

The size of the plot is important. Plots of only 1m2 in size will allow investigations into infiltration and the effects of rainsplash but are too small for studies of overland flow except as a transporting agent for splashed particles. Plots must be at least 10 m long for studies of rill erosion. Much larger plots are required for evaluating farming practices such as strip cropping and terracing.

Gerlach troughs

An alternative method of measuring sediment loss and runoff was developed by Gerlach (1966) using simple metal gutters, 0.5 m long and 0.1m broad, closed at the sides and fitted with a movable lid (Fig. 6.2). An outlet pipe runs from the base of the gutter to a collecting bottle. In a typical layout, two or three gutters are placed side-by-side across the slope and groups of gutters are installed at different slope lengths, arranged *en echelon* in plan to ensure a clear run to each gutter from the slope crest. Because no plot boundaries are used, edge effects are avoided. It is normal to express soil loss per unit width but if an areal assessment is required, it is necessary to assume a catchment area equal to the width of the gutter times the length of the slope. A further assumption is that any loss of water and sediment from this area during its passage downslope is balanced by inputs from adjacent areas. This assumption is reasonable if the slope is straight in plan. On slopes curved in plan, the catchment area must be surveyed in the field. This disadvantage is offset by the flexibility of monitoring soil loss at different slope lengths and steepnesses within an open system. Because of their cheapness and simplicity, Gerlach troughs can be employed for sample measurements of soil loss at a large number of selected sites over a large area.

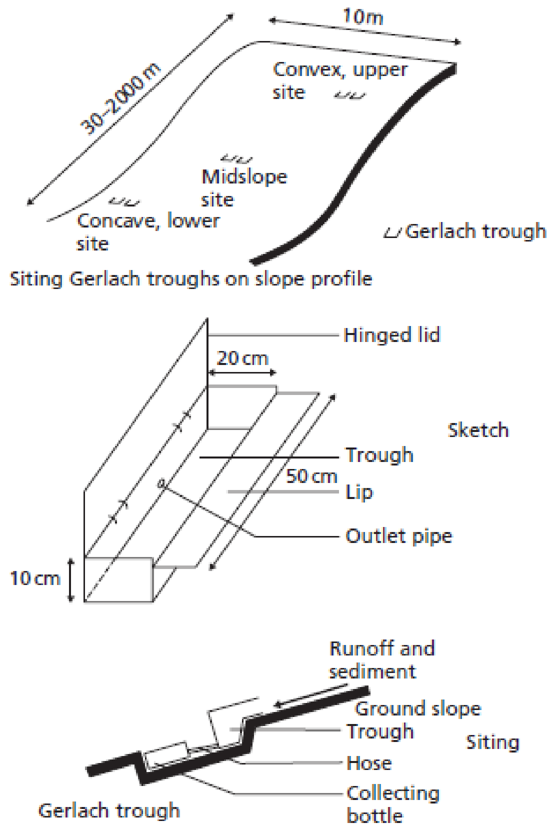

Fig. 6.2 Gerlach troughs.

Changes in ground level

The simplest way of measuring changes in ground level over time is to use what is technically known as an erosion pin but, in reality, is a 250–300 mm long nail, 5 mm in diameter, driven through a washer into the soil (Emmett 1965). The head of the nail should be some 20–30mm above the soil surface, the washer flush with the surface and the base of the nail sufficiently far into the ground not to be disturbed by changes in soil volume due to wetting-and-drying or freeze–thaw. Periodic measurements of the gap between the head of the nail and the washer indicate the extent to which the surface has been lowered; where the washer has become buried, the depth of the material above the washer indicates the depth of deposition. Measurements need to be taken over many years before a consistent pattern of ground lowering can be separated from shorter-term fluctuations in level due to changes in soil volume. A large number of pins, usually installed on a grid system, is needed to obtain representative data over a large area.

A disadvantage of erosion pins is that they can be easily disturbed by livestock and wildlife or stolen by the local population, who can find supposedly better uses for iron or steel nails. They can also be difficult to relocate in subsequent surveys. An alternative approach is to establish a network of metal pegs, set unobtrusively in concrete at ground level so that their position remains stable over time. A portable aluminium girder is placed across any two adjacent pegs from which vertical readings of the depth to the soil surface can be taken at regular intervals. Between readings the girder is removed. The method, pioneered by

Hudson (1964) on rangeland in Zimbabwe, is known as the erosion bridge. Again long-period measurements are needed to isolate trends in erosion or deposition from short-term fluctuations in soil level.

Splash erosion measurements

Erosion plots, Gerlach troughs, erosion pins and erosion bridges provide information on erosion by rainsplash, overland flow and rills combined. Attempts to assess the relative contributions of each are based on separate measurements of splash erosion and rill erosion with the balance being attributed to overland flow. Splash erosion has been measured in the field by means of splash boards (Ellison 1944) or small funnels or bottles (Sreenivas et al. 1947; Bollinne 1975). These are inserted in the soil to protrude 1–2mm above the ground surface, thereby eliminating the entry of overland flow, and the material splashed into them is collected and weighed. An alternative approach is the field splash cup (Morgan 1981; Fig. 6.3), where a block of soil is isolated by enclosing it in a central cylinder and the material splashed out is collected in a surrounding catching tray. Because the quantity of splashed material measured per unit area depends upon the diameter of the funnels and cups, the following correction has to be applied to determine the real mass of particles detached by splash:

$$MSR = MSe^{0.054D} \qquad (6.1)$$

where *MSR* is the real mass of splashed material per unit area (gcm^{-2}), *MS* is the measured splash per unit area (gcm^{-2}) and *D* is the diameter of the cup or funnel (cm) (Poesen and Torri 1988).

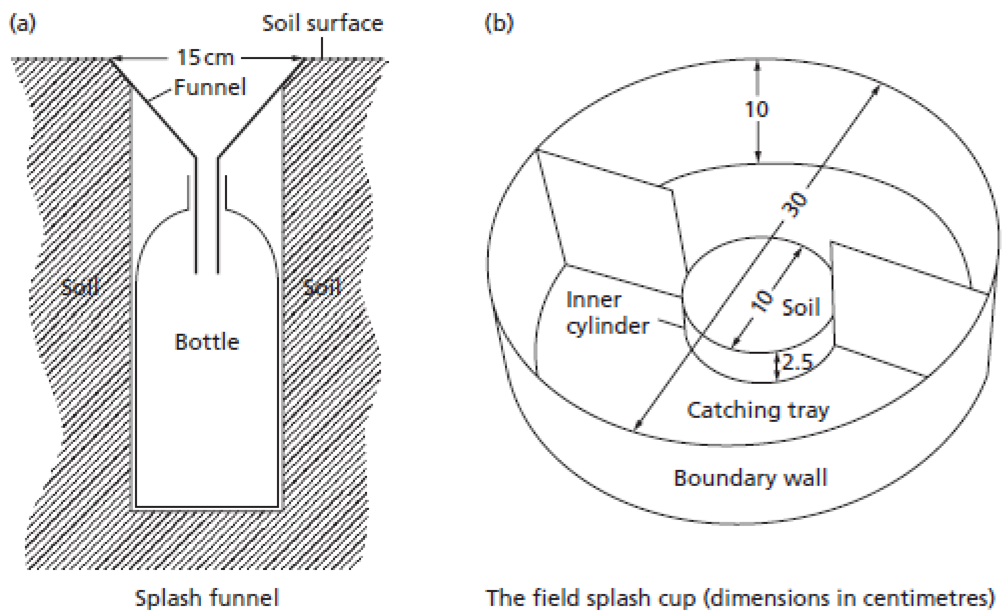

Fig. 6.3 Methods of measuring splash erosion in the field, after (a) Bollinne (1975) and (b) Morgan (1981).

Rill erosion measurement

The simplest method of assessing rill erosion is to establish a series of transects, 20–100 m long, across the slope and positioned one above the other. The cross-sectional area of the rills is determined along two successive transects. The average of the two areas multiplied by the distance between the transects gives the volume of material removed. By knowing the bulk density of the soil, the volume is converted into the weight of soil loss and this, in turn, is related to an area defined by the length and distance apart of the transects. Since this method ignores the contribution of interrill erosion to the sediment carried in the rills and also depends upon being able to identify distinctly the edge of the rills, it is likely to underestimate rill erosion by 10–30 per cent.

Gully erosion measurement

Erosion from relatively small gullies can be assessed using the same profiling technique as described above for rills. For larger gullies, sequential surveys using aerial photography are more suitable. More recent surveys of gullies use large-scale (1 : 10,000) aerial photography to construct high resolution digital elevation models (DEMs). Rates of gully erosion are calculated from differences in elevation between DEMs of different dates. Digitally generated DEMs can match the accuracy of traditional analytical photogrammetric techniques and are much faster to produce.

6.2.2 Catchments

Sediment yield

The sediment yield of a catchment is obtained from measurements of the quantity of sediment leaving a catchment along the river over time. Recording stations are established at the exit point for the automatic measurement of discharge, using weirs and depth recorders, and suspended sediment concentrations in the river water. Water samples are taken at set times with specially designed integrated sediment samplers, or the sediment concentration is monitored continuously by recording the turbidity of the water. Bucket samples are not recommended because they contain only the surface water and cannot provide information on the sediment being transported throughout the depth and width of the river channel. With measurements made at set times, there is a need to extrapolate the data to cover the period between samples. The standard approach is to establish a sediment discharge rating curve in which the sediment concentration (C) is related to the water discharge (Q) by the equation:

$$C = aQ^b \qquad (6.2)$$

The accuracy of this method is highly dependent on the frequency of sampling. The likelihood of underestimation increased as the sampling frequency decreased, since, with longer sampling intervals, the record is likely to include fewer flood events. Monthly sampling for estimating annual sediment yield of larger catchments, 1000–3000km^2 in size, can result in underestimations of 60–80 per cent. Of course, it should be recognized that the turbidity meter does not give a true record because the measurements are subject to errors associated with the influence of the particle size of the sediment load, the magnitude of the sediment concentration, the presence of organic matter and the need to keep the sensors clear of algae. Despite these problems, the method is currently the best available to provide estimates of suspended sediment yield, especially if high frequency data are

needed. It should be recognized, however that, because of the need for regular calibration and maintenance, such data come at greater cost compared to using rating curves.

Reservoir surveys
Sedimentation rates in lakes and reservoirs can indicate how much erosion has taken place in a catchment upstream, provided the efficiency of the reservoir as a sediment trap is known.

Using manual soundings of depth from a boat, a contour map was made of the bottom of the reservoir. The volume of the reservoir is obtained by adding up the partial volumes (V):

$$V = h(A + B)/2 \qquad (6.3)$$

where V is the volume of sediment (m^3), h is the upper contour interval (m), A is the area of the upper contour (m^2) and B is the area of the lower contour interval (m^2). To this total, the volume below the lowest contour is added, calculated as the product of the area of the lowest contour and the mean depth to that contour from the bottom. The reservoir volume is then compared with the initial volume. The reduction in volume represents the volume of sediment accumulated in the reservoir. Assuming an average dry bulk density of $1.5 Mgm^{-3}$, the volume is converted into a mass and divided by the area of the catchment upstream to give an erosion value in t ha^{-1}. This is further adjusted by assuming that the sediment in the reservoir represented about half that eroded from the catchment. Dividing the adjusted total by the number of years since the reservoir is built gave a mean annual erosion rate. More rapid reservoir surveys can be made using an echo-sounder to obtain depth readings, an electro-distance measuring theodolite or laser theodolite to fix the position of the sounding, and a digital elevation model (*DEM*) to produce the contour map. Sedimentation rates in farm ponds can be analysed using a similar methodology.

Tracers
The most commonly used tracer in soil erosion measurement is the radioactive isotope, caesium-137 (137Cs). Caesium-137 was produced in the fall-out of atmospheric testing of nuclear weapons from the 1950s to 1970s. It was distributed globally in the stratosphere and deposited on the earth's surface in the rainfall. Regionally, the amount deposited varies with the amount of rain but,within small areas, the deposition is reasonably uniform. The isotope is strongly and quickly adsorbed to clay particles within the soil. By analysing the isotope content of soil cores collected on a grid system varying in density from 10×10 to 20×20m, the spatial pattern of isotope loading is established. Figure 6.4, shows a typical situation. In the pasture land at the top of the slope, the isotope is concentrated at the surface; its presence in small amounts at depth is the result of earthworm activity in the soil. On the arable site, the isotope is more uniformly distributed with depth as a result of disturbance of the soil by ploughing. The decline in isotope loading by about 40 per cent on the steeper slope is a result of erosion. At the bottom of the slope, there is an increase in loading due to deposition of material. Since the deposition has been active for some years, some of the isotope lies below the present plough depth. Spatial variations in isotope loading in comparison with those at a reference site, usually in either woodland or grassland, have been interpreted successfully, in many parts of the world, as indicating the

patterns of erosion and deposition (Ritchie & Ritchie 2001). When comparing the results with those from erosion plots, it should be noted that they reflect the sum of all the processes by which soil can be redistributed over a field or a hillside and not just the outcome of interrill and rill erosion.

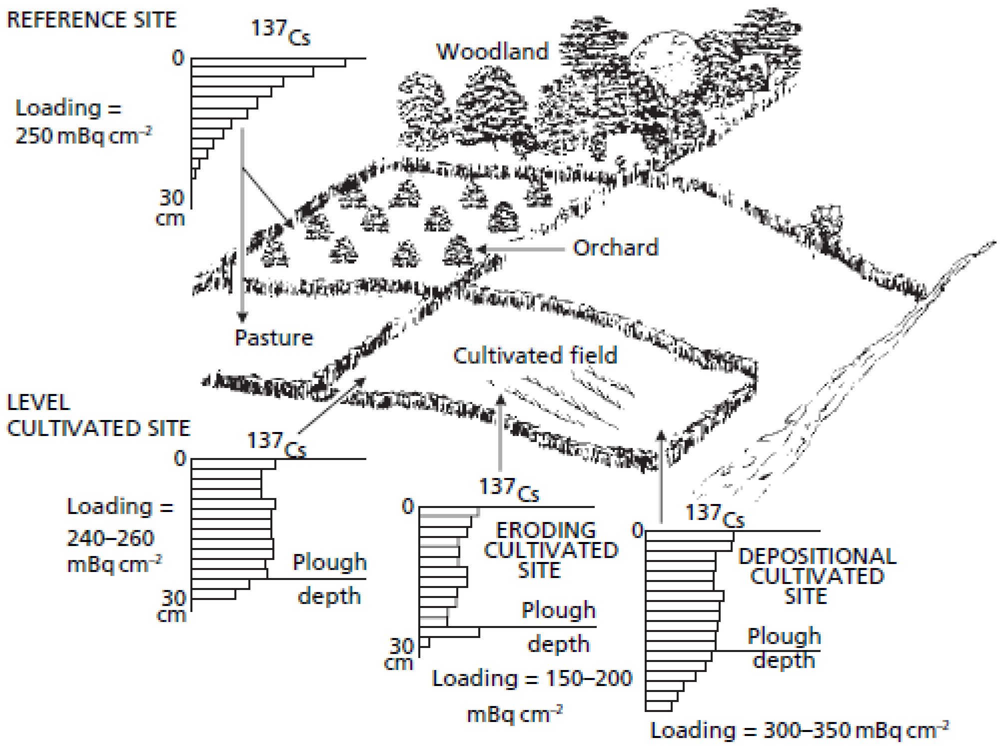

Fig. 6.4 Schematic representation of the effect of erosion and deposition upon the loading and profile distribution of caesium-137

The method provides qualitative information on the patterns of soil erosion and deposition in the landscape over a period of 30–50 years. A conversion model is required to turn this information into estimates of erosion rates (Walling et al. 2002a). The simplest and most widely used model is the proportional approach (Mitchell et al. 1980; De Jong et al. 1983):

$$Y = 10 \times \frac{BdX}{100TP} \qquad (6.4)$$

where Y is mean annual soil loss (t ha^{-1} yr^{-1}), B is the bulk density of the soil (kgm^{-3}), d is the depth of the plough or cultivated layer (m), T is the time that has elapsed since the start of the accumulation of 137Cs and P is the ratio of the concentration of 137Cs in the mobilized sediment to that in the original soil. The term X is the percentage reduction in the total 137Cs inventory relative to the reference value, i.e.

$$X = \left(\frac{A_{ref} - A}{A_{ref}}\right) \times 100 \qquad (6.5)$$

where *Aref* is the caesium loading at the reference site (Bq m^{-2}) and A is the loading at the sample point. For sites of deposition, X is positive and P is the ratio of the concentration of 137Cs in the deposited sediment to that in the mobilized sediment. The method tends to

underestimate erosion rates because it does not take into account the dilution of 137Cs concentration on erosion sites through the incorporation of soil from below the original plough depth.

6.2.3 Sand traps

The techniques for measuring wind erosion are less well established than those for monitoring water erosion. The problem is to design an aerodynamically sound trap to catch soil particles while allowing the air to pass freely through the device. The build-up of back pressure causes resistance to the wind that is deflected from the traps. By careful adjustment of the ratios between the sizes of inlet, outlet and collecting basins, a satisfactory trap can be produced. An example is the Bagnold catcher (Fig. 6.5), consisting of a series of boxes placed one above the other so as to catch all the particles moving through a unit width of air flow at different heights. The disadvantage of the Bagnold catcher is that it cannot be reoriented as wind direction changes. Devices such as the Big Spring Number Eight sampler (Fig. 6.6) and the Wilson and Cooke bottle sampler (Fig. 6.7) overcome this by being mounted at different heights on a mast to which a wind vane is attached, allowing the whole apparatus to rotate so that the capture tubes always face the wind. These catchers have efficiencies between 75 and 100 per cent, depending on the size of the particles being carried in the wind. The material caught in the traps is collected and weighed after each period of observation.

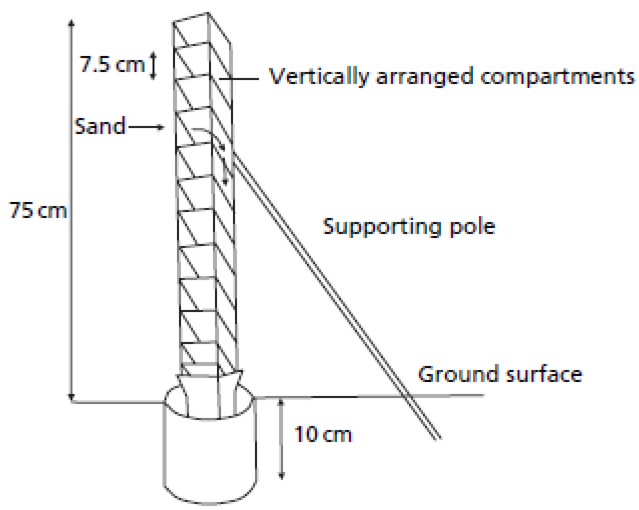

Fig. 6.5 Bagnold sand catcher.

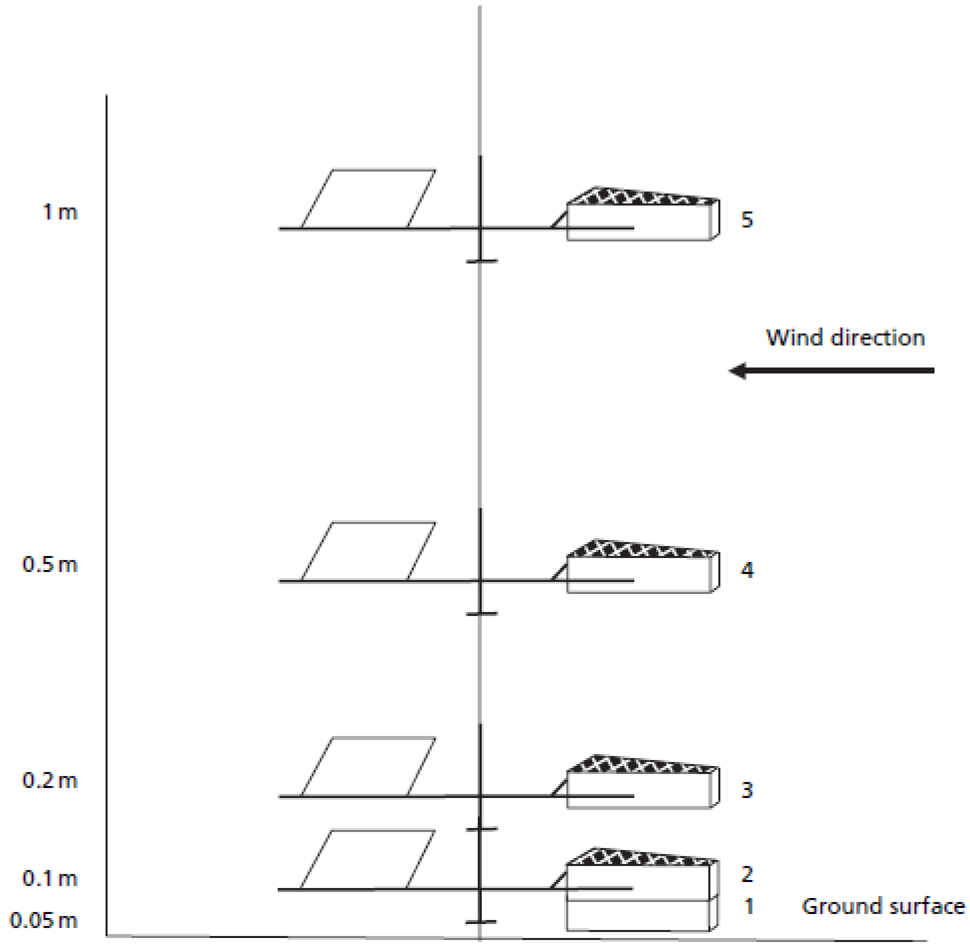

Fig. 6.6 Big Spring Number Eight sampler. Sizes of inlets for the different catchers are: (1) 10× 20mm; (2) 20 ×20mm; (3) 30 ×20mm; (4) 50×20mm; and (5) 50 ×20mm.

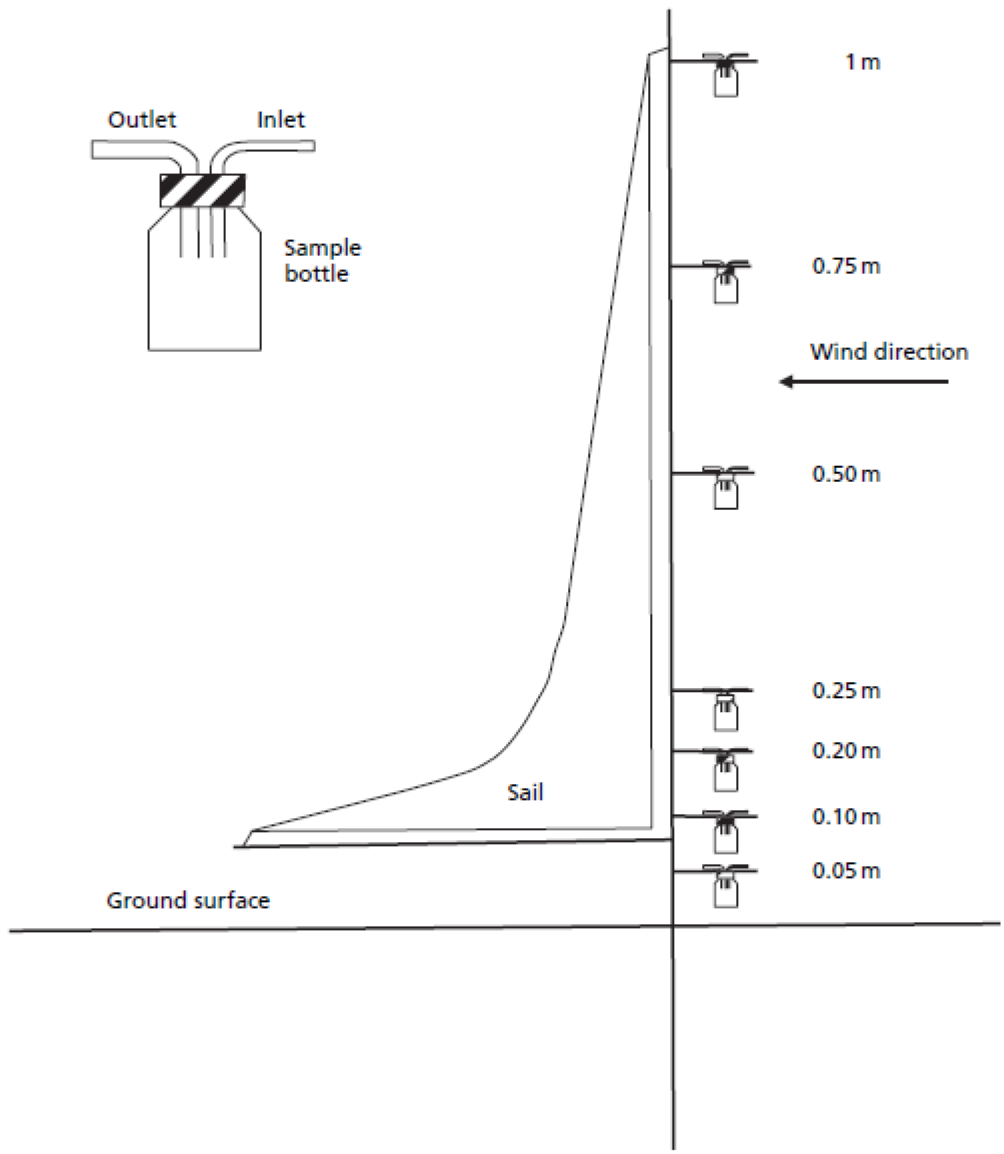

Fig. 6.7 Wilson and Cooke bottle sampler. The dimensions can be varied according to the material used to build the sampler. The sampler used by the National Soil Resources Institute had an inlet pipe of 10mm diameter and an outlet pipe of 15mm diameter.

6.3 Laboratory experiments

The key questions arising with laboratory studies concern the scale of the experiment, the greater influence of boundary effects and the extent to which field conditions are simulated. It is not usually possible to construct a scaled-down version of field conditions – for example, by using a small plot to represent a large hillslope – because scale-equivalence cannot be maintained in raindrops and soil particles without affecting their basic properties or behaviour. It is therefore preferable to treat laboratory experiments as representing true-to-scale field simulation. Even so, many factors cannot be properly

simulated and, unless the laboratory facilities are very large, nor can processes such as rill erosion and the saltation of soil particles by wind.

5.3.1 Rainfall simulation

Many laboratory studies centre on the use of a rainfall simulator, which is designed to produce a storm of known energy, intensity and drop-size characteristics that can be repeated on demand. The most important design requirements of a simulator are that it should reproduce the dropsize distribution, drop velocity at impact and intensity of natural rainfall with a uniform spatial distribution and that these conditions should be repeatable. The need to reproduce the energy of the natural rainfall for the intensity being simulated is generally regarded as less important.

Rainfall simulators are classified according to the drop-formers used. The most common are tubing tips, either hypodermic needles or capillary tubes and nozzles .None accurately recreates all the properties of natural rain. There is insufficient height in most laboratories for water drops to achieve terminal velocity during fall, so their kinetic energy is low. To overcome this, water is released from low heights under pressure. This results in too high an intensity and, because the increase in pressure produces small drop sizes, unrealistic drop-size distributions. The intensity can be brought down by reducing the frequency of rain striking the target area, either by oscillating the spray over the target or by intermittently shielding the target from the spray. It should be noted, however, that this only reduces the intensity measured as the amount of water applied over a given time period; the instantaneous intensity and impact energy of the simulated rain are not reduced. True spatial uniformity is also virtually impossible to achieve.

Studies of splash erosion are made in the laboratory by filling containers with soil, weighing them dry, subjecting them to a simulated rainstorm of pre-selected intensity and measuring the weight loss from the containers on drying. In this way different soils can be compared for their detachability. The standard container is the splash cup first used by Ellison (1944), a brass cylinder 77 mm in diameter and 50mm deep with a wire mesh base. A thin layer of cotton wool or sponge rubber is placed in the bottom of the cup, which is then filled with the soil, oven dried to a constant weight and weighed. The soil in the cup is brought to saturation prior to rainfall simulation. The soil level in the cup needs to be a few millimetres below the rim, as otherwise the erosion is accelerated by material washing off the surface during the early part of the storm; this effect can be enhanced if the initial raindrop impacts create a pitted or rough surface or if the surface is too loosely packed. Towards the end of the storm, the splash loss will be reduced because the level of the soil within the cup becomes too low and splashed particles are intercepted by the rim of the cup.

5.3.2 Runoff simulation

Where the target is in the form of a small soil plot, the rainfall simulator may be supplemented by a device to supply a known quantity of runoff at the top of the plot, instead of relying solely on runoff resulting from the rainfall. The set-up at the Experimental Geomorphology Laboratory, University of Leuven, Belgium, consists of an

aluminium and plexiglass flume, 4 m long and 0.4m wide, which is fed by water at its upper end through a cylinder with ten openings. The discharge is controlled by a tap through which water is pumped to the cylinder from a container; a constant water level is maintained in the container. The slope of the flume can be adjusted to different steepnesses and rainfall simulators positioned over the top. The main problem with a small flume of this type is that edge effects are difficult to eliminate. They can be reduced, however, by collecting the sediment and runoff washing off a narrow strip down the centre of the plot instead of collecting for the whole plot width. The short length of the flume makes it difficult to simulate rill erosion although the supply of runoff at the top of the slope can be adjusted to simulate the effect of different slope lengths. Sediment can also be added to the runoff upslope of the test soil.

5.3.3 Wind tunnels

Almost all the basic studies on wind erosion have been carried out in the laboratory in wind tunnels.Wind is supplied by a fan that either sucks or blows air through the tunnel. The tunnel is shaped so that air enters through a honeycomb shield, serving as a flow straightener, into a convergence zone, where flow is constricted, passes through the test section and leaves through a divergence zone, in which flow is diffused. A mesh screen at the outlet traps most of the sand particles, while allowing the air to blow through without the build-up of back pressure. Realistic wind profiles are produced only in the test section and the value of the tunnel depends on the length of this. Small tunnels, such as the one described by De Ploey and Gabriels (1980) with a test section only 1.5 m long, do not permit a satisfactory sand flow to be attained. A test section at least 15 m long is required for this, though Bagnold (1937) was able to simulate sand flow in a 10-m long tunnel by feeding a stream of sand into its mouth.

Most of the tunnels used for soil erosion research are of the open-circuit type where air is drawn in from outside. These are cheaper than closed-circuit tunnels and afford easier control over the air flow in the test section because there is less upstream contact between the air and the boundary walls and therefore less turbulence. In a closed-circuit tunnel (Fig. 6.8), the fan is located in a loft above the test section and dry centrally heated air is forced downwards and into the test section through a funnel where unwanted turbulence is likely to be induced. Closed-circuit tunnels are less noisy and give good control over air humidity. The latter is important because it influences the critical wind velocity for particle movement. Soil trays are placed on the floor of the tunnel in the test section and these can be removed for weighing. Thus the amount of erosion can be determined by weight loss.

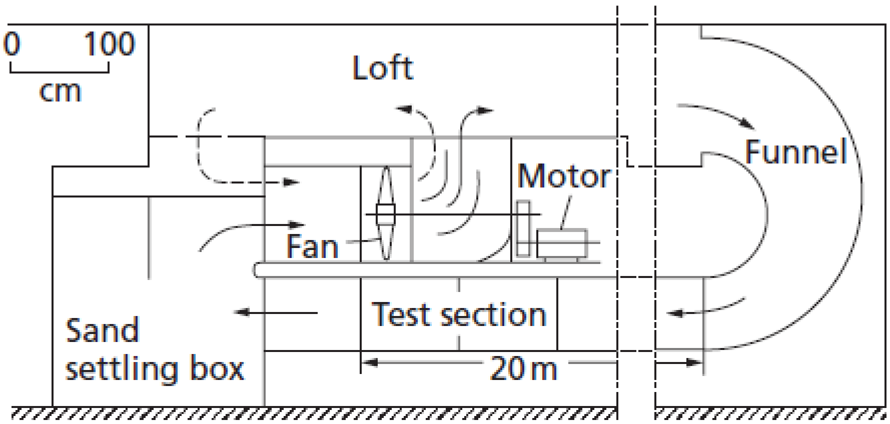

Fig. 6.8 Details of a closed-circuit wind tunnel

07	Principles of erosion control

7.1 Introduction

Soil erosion takes place both due to natural causes and anthropogenic factors. The adverse effects of uncontrolled soil erosion are loss of valuable top soil lowering crop productivity per unit of land, sedimentation in rivers and irrigation canals drawing water from the rivers reducing their carrying capacity, sedimentation of reservoirs reducing their active life, structural damages to the buildings and formation of gullies and ravines, to name a few important ones. Soil erosion control measures are adopted to reduce or minimize the intensity of the aforesaid adverse effects. Catchment Area Treatment (CAT) is adopted to reduce soil loss from catchments due to runoff flow, after ascertaining erosion severity on sub-watershed basis. CAT comprises mechanical (engineering) and vegetative (afforestation) measures. Mechanical and vegetative practices on agricultural lands are employed on the milder slopes for conservation of soil, by farming across the slope of the land. The basic principle underlying this approach is to cause reduction in the effect of the runoff velocity and, thereby reduce soil erosion. On steeper slopes, mechanical measures (such as terracing) and other structures are constructed to reduce the effect of the slope on runoff velocity. The following types of vegetative and mechanical practices are being used at present:

7.1.1 Vegetative Practices

(i) Contouring

(ii) Strip cropping

(iii) Tillage operations

(iv) Mulching

7.1.2 Mechanical Practices

(i) Terracing

(ii) Bunding

(iii) Grassed waterways and diversions

Vegetative practices are described in this lesson and mechanical practices are described in the subsequent lessons.

7.2 Contouring

Contouring is the practice of cultivation along contours, as illustrated in Fig. 7.1, laid across the prevailing slopes of the land where all farming operations, such as ploughing, sowing, planting, cultivation, etc. are carried out approximately on contours.

Fig. 7.1. Contouring

The intercultural operations create contour furrows, which along with plant stems act as barriers to the water flowing down the slope. In between two adjacent ridges runoff or irrigation water is detained for a longer period of time, which in turn, increases the opportunity time for the water to infiltrate into the soil and increase the soil moisture. To lay a contour farming system, contour guide lines are laid out first and tillage operations are carried out simultaneously. Experimentally it has been observed (Antal, 1986) that reduction in the intensity of soil erosion, owing to water, by contour ploughing is about 30% of that by ploughing along the slope, and there is increase in moisture content by about 40% and reduction in surface runoff by about 13%. Furrow cultivation

on contours has been found to be the most effective soil conservation measure. Contour farming is recommended for lands with the slope range of 2 to 7%.

7.3 Strip Cropping

Strip cropping is the practice of growing strips of crops having poor potential for erosion control, such as root crops (which are intertilled crops), cereals, etc., alternated with strips of crops having good potential for erosion control, such as fodder crops, grasses, etc. which are close growing crops. Strip cropping is a more intensive farming practice than farming only on contours. Close growing crops act as barriers to runoff flow and reduce the runoff velocity generated from the strips of intertilled crops, and eventually reduce soil erosion.

7.3.1 Purpose of Strip Cropping is to:

(a) Reduce soil erosion from water and transport of sediment and other water-borne contaminants

(b) Reduce soil erosion from wind

(c) Protect growing crops from damage by wind-borne soil particles.

7.3.2 Methods of Strip Cropping:

(a) Contour strip cropping

(b) Field strip cropping

(c) Buffer strip cropping

(a) Contour Strip Cropping

In contour strip cropping, alternate strips of crops are sown more or less along the contours, similar to contouring. Suitable rotation of crops and tillage operations are followed during the farming operations. Fig. 7.2 shows contour strip cropping.

Fig. 7.2. Contour strip cropping.

(b) Field Strip Cropping

In a field layout of strip cropping, as shown in Fig. 8.3, strips of uniform width are laid out across the prevailing slope, while protecting the soil from erosion by water.

Fig. 7.3. Field strip cropping

To protect the soil from erosion by wind, strips are laid out across the prevailing direction of wind. Such practices are generally followed in areas where the topography is irregular, and the contour lines are too curvy for laying the farming plots.

(c) Buffer Strip Cropping

Buffer strip cropping is practiced where uniform strips of crops are required to be laid out for smooth operation of farm machinery, while farming on a contour strip cropping layout. Buffer strips of legumes, grasses and similar other crops are laid out between the contour strips as correction strips, as illustrated in Fig. 7.4. Buffer strips provide very good protection and effective control of soil erosion from strips of intertilled crops.

Fig. 7.4. Buffer strip cropping.

7.4 Tillage Operations

Tillage operations carried out for conservation of soil are

(a) Minimum tillage

(b) No tillage

(c) Strip tillage

The special benefit of tillage operations are to:

(1) Increase the soil infiltration capacity

(2) Improve the soil moisture retention capacity

(3) Improve the humus content of soil

(4) Create a rough land surface to protect it against erosion by water or wind.

Minimum Tillage

It is the operation in which tillage and sowing are combined in one operation, as illustrated in Fig. 7.5. Such operations create a coarse soil surface and fine lumps of soil between rows. The loose and porous texture of the soil allows a good infiltration capacity. The surface runoff by this operation is reduced by about 35% and soil erosion by about 40%.

Fig. 7.5. Minimum tillage

No Tillage

In the no-tillage system of operation, the soil surface is not disturbed much and left more or less intact. The operations performed are under cutting, loosening and drying of the upper soil layer, so that weeds do not grow and stubbles of the previous crop remain as such in the field. When there are no weeds, the under cutting operations are not required, and seeds are sown directly into the soil by special types of seed drills. Incidentally, the shifting (Jhoom) cultivation, as illustrated in Fig. 7.6, prevalent in north-east India, is perhaps the best example of no-tillage traditionally followed since hundreds of years. In jhoom cultivation, a part of a forest land is burnt to clear it and seeds are manually dibbled without any ploghing or major soil disturbance. When the naturally occurring soil nutrients are exhausted, the land is abandoned and a new piece of forest land is selected for burning and subsequent cultivation. However, this method of cultivation has a risk of aggravating soil erosion problem if practiced on hill slopes (which usually is the case).

Fig. 7.6. Terrace rice cultivation in Phek district (Jhoom Cultivation).

It is found that reduction in soil erosion up to 70% has been obtained through this method of tillage.

Strip Tillage

This operation is an improvement over the no tillage system. In this type of cultivation, narrow strips of approximately 0.2 m width and 0.1 m depth are generally laid out following the contour, and the land between the strips left uncultivated. These are also called loosening strips. In the constructed narrow strips, there are no stubbles, which help in sowing operations and facilitate better plant growth. Fig. 7.7 and 7.8 shows strip tillage done by tractor drawn implement and animal drawn implement.

Fig. 7.7. Strip-tillage

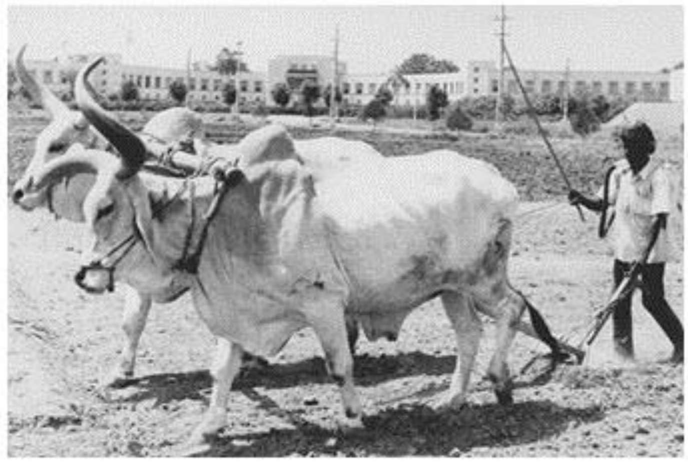

Fig. 7.8. Bullock-drawn shallow chisel desi plough

The farm implement normally used for conservation tillage operations are:

(1) V-shaped sweeps

(2) Arrow shaped blades for control of erosion caused by water

(3) Chisel like blades for control of erosion caused by wind

(4) Rod weeders etc.

7.5 Mulching

Mulches (soil covers) are used to minimize rain splash, reduce evaporation, control weeds, reduce temperature of soil in hot climates, and allow temperature which is conducive to microbial activity. A view of munches is shown in Fig. 7.9. Stubbles, trash, other type of vegetation and polythene are some of the most common types of mulches used. These materials are spread over the land surface. Mulches help in reducing the impact energy of rain water, prevent splash and destruction of soil structure, obstruct the flow of runoffs to reduce their velocity and prevent inter-rills erosion, and help in improving the infiltration capacity by maintaining a conductive soil structure at the top surface of the land.

Fig. 7.9. Mulching

08	Introduction to contouring, strip cropping. Contour bund. Graded bund and bench terracing.

8.1 Contouring

Contouring is the practice of cultivation along contours, as illustrated in Fig. 8.1, laid across the prevailing slopes of the land where all farming operations, such as ploughing, sowing, planting, cultivation, etc. are carried out approximately on contours.

Fig. 8.1. Contouring

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(b) Field Strip Cropping

In a field layout of strip cropping, as shown in Fig. 8.3, strips of uniform width are laid out across the prevailing slope, while protecting the soil from erosion by water.

Fig. 8.3. Field strip cropping.

To protect the soil from erosion by wind, strips are laid out across the prevailing direction of wind. Such practices are generally followed in areas where the topography is irregular, and the contour lines are too curvy for laying the farming plots.

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Fig. 8.4. Buffer strip cropping.

8.3 Mechanical Measures for Water Erosion Control

Mechanical practices are engineering measures used to control erosion from slopping land surfaces and thus land surface modification is done for retention and safe disposal of runoff water. In the design of such practices, the basic approach is (i) to increase the time of stay of

runoff water in order to increase the infiltration time for water, (ii) to decrease the effect of land slope on runoff velocity by intercepting the slope at several points so that the velocity is less than the critical velocity, and (iii) to protect the soil from erosion caused by the runoff water. The mechanical measures adopted for soil and water conservation are: bunding, terracing etc.

8.4 Bunds (Contour Bunds, Graded Bunds) and their Design

Bund is an engineering measure of soil conservation, used for creating obstruction across the path of surface runoff to reduce the velocity of flowing water. It retains the running off water in the watershed and thus to helps to control soil erosion. Bunds are simply embankment like structures, constructed across the land slope. Different types of bunds are used for erosion control and moisture conservation in the watersheds. When the bunds are constructed along the contours with some minor deviation to adapt to practical situation, they are known as **contour bunds**. If the bunds are constructed with some slope, they are known as **graded bunds**. No farming is done on bunds expects at some places, where some types of stabilization grasses are planted to protect the bund. The choice of the types of bund is dependent on land slope, rainfall, soil type and the purpose of the bund in the area. The contour bunds are recommended for areas with low annual rainfall (< 600 mm) agricultural fields with permeable soils and having a land slope of less than 6%, while graded bunds are used for safe disposal of excess runoff in areas with high rainfall and relatively impervious soil.

In India, contour and graded bunding have been practiced for a long time and the Indian farmers have very good knowledge about it. From the experience, it has been found that bunds could stand well in shallow, medium and medium deep soils. In deep black soil, due to cracks in dry condition, the bunds fail. Through these cracks, water continues to flow and big breaches are usually created. This results in severe damage to the fields. Although various erosion problems exist in black cotton soils, contour bunding cannot be taken up in such soils successfully.

8.4.1 Contour Bunds

Contour bunds are laid out in those areas which have less rainfall and permeable soils. The major requirements in such areas are prevention of soil erosion and conservation of rain water in the soil for crop use. To maximize the conservation of rainwater in the soil, no longitudinal slope is provided to the field strip. In such a system of bunding, the bunds are designed to be laid out on contours with minor adjustments, wherever necessary.

The main functions of contour bunds are:

1. It reduces the length of slope which in turn reduces the soil erosion.
2. The water is impounded for some time and gets recharged into the soil which helps in crop cultivation.

The limitations of contour bunds are:

1. The contour bunds are suitable for those areas, which receive the annual rainfall less than 600 mm
2. It is not suitable for clayey soils
3. Contour bunding is not suitable on the land slopes greater than 6%.

8.4.2 Graded Bunds

Graded bunds are laid out in areas where the land is susceptible to water erosion, the soil is less permeable and the area has water logging problems. A graded bund system is designed to dispose of excess runoff safely form agricultural fields. A graded bund is laid out with a longitudinal slope gradient leading to outlet. The gradient can be either uniform or variable. The uniformly-graded bunds are suitable for areas where the bunds need shorter lengths and the runoff is low. The variable-graded bunds are required where bunds need longer lengths, owing to which the cumulative runoff increases towards the outlets. In these types of bunds, variations in the grade are provided at different sections of the bund to keep the runoff velocity within the desired limits so as not to cause any soil erosion.

The limitations of the system are:

- Due to crossing of farm implements, the bunds are disturbed and some soil is lost.
- Proper maintenance is required at regular interval.

8.4.3 Design Specification of Bunds

The following parameters should be considered for bund design:

1. Type of Bund: The type of bund (contour or graded bund) to be constructed depends upon the rainfall and soil condition. Contour bunds are preferred for construction in areas receiving annual rainfall less than 600 mm and where soil moisture is a limiting factor for crop production. Graded bunds are recommended in heavy and medium rainfall areas. The grade to be provided to the bund may vary from 0.2% to 0.3%.

2. Spacing of the Bunds: The basic principles to be adopted for deciding the spacing of bunds are: (1) the seepage zone below the upper bund should meet the saturation zone of the lower bund; (2) the bunds should check the water at a point where the water attains erosive velocity and (3) the bund should not cause inconvenience to the agricultural operations.

For determining the spacing of the bunds the following formula is used:

$$V.I. = \frac{S}{a} + b \qquad (6.1)$$

where,

V.I. = vertical interval between consecutive bunds,

S = land slope (percent) and

a and b = constants, depend upon the soil and rainfall characteristics of the area.

The above equation is area specific. It can be modified for areas with different rainfall amounts.

1. For the areas of heavy rainfall:

$$V.I. = 10S + 60 \tag{6.2}$$

2. For the areas having low rainfall

$$V.I. = 15S + 60 \tag{6.3}$$

In which, VI is in cm and S is in percent.

The bund spacing can not be easily located on the ground on the basis of vertical interval. But the horizontal interval (spacing) can be easily measured on the land surface. For this purpose, the relationship between horizontal and vertical spacing is important and is given below.

H.I. = V.I. / S

Here, H.I. indicates the horizontal distance of the bund and V.I. is the vertical interval.

3. Size of the Bund: The size of bund includes its height, top width, side slopes and bottom width. The height of bunds mainly depends upon the slope of the land, spacing of the bunds and the maximum intensity of rainfall expected in the area. Once the height of the bund is determined, other dimensions of the bund viz., base width, top width and side slopes are determined using the information on the nature of the soil. Depending on the amount of water to be intercepted, the height of the bund can be calculated as given below (Fig. 6.1).

Let X = height of the bund, L = distance between bunds, V = vertical interval between bunds, and W = width of water spread.

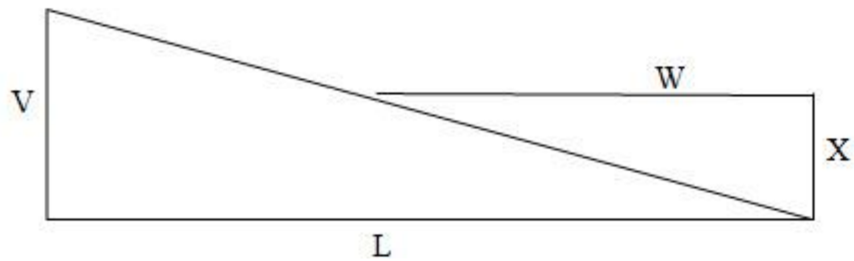

Fig. 6.1. Basic diagram for deriving the height of bund.

$$\frac{W}{L} = \frac{X}{V} \quad or \quad W = \frac{LX}{V} \tag{6.4}$$

Considering 1m length of the bund, amount of water stored = ½ WX

Substituting for W from Eqn. 6.4, amount of water stored

$$= 0.5\left(\frac{LX^2}{V}\right) \tag{6.5}$$

Assuming that any time the maximum rainfall, which the bunds have to withstand, is 15 cm high; water retained by 1 m length of the bund

$$= \frac{15}{100}(L.1) = \frac{3L}{20} \tag{6.6}$$

Now equating both these values:

$$0.5\left(\frac{LX^2}{V}\right) = \frac{3L}{20}$$

Height of the bund, $$X = \sqrt{\frac{3V}{10}} \tag{6.7}$$

When, the land slope is expressed as S per cent.

$$V = LS/100$$

$$x = \sqrt{\frac{3LS}{1000}} \qquad (6.8)$$

L and X are in meters and S is the per cent slope. This is the theoretical height and suitable free board is added to arrive at the practical height of the bund.

Base width of the bund depends upon the hydraulic gradient of water in the soil. Side slopes are dependent upon the angle of repose of the soil. A general value of the hydraulic gradient assumed is 1:4. Side slopes of the bund recommended for different soils are given in Table 6.1.

Table 6.1. Side slopes of the bunds recommended for different soil types (Source: Murthy, 1994)

Side slopes	1.5 to 1	2 to 1	2.5 to 1
Soil types	Red Gravel	Light Sandy loam	Sand
	Light red loam	Clay	
	Black loam	Black cotton soil	
	White gravel	Soft decomposed rock	

Some of the typical cross sections of bunds are shown in Table 6.2. Usually a higher size of the bunds than required by the hydraulic considerations is adopted to allow for the settlement and poor maintenance by the cultivators.

Table 6.2. Typical bund cross-sections for scarcity areas

(Source: Murthy, 1994)

Soil Types	Top width (m)	Bottom width (m)	Height(m)	Side Slope
Full maximum or soil layer up to 7.5 cm	0.45	1.95	0.75	1:1
Soil layer from 7.5 cm to 23 cm	0.45	2.55	0.83	1.25 :1
Full soil or soil layer from 23 cm to 45 cm	0.53	3.0	0.83	1.50: 1
Full soil 45 cm to 80 cm	0.60	4.2	0.90	2:1

4. Length of Bund. The length of bund is determined by calculating the horizontal interval of the bund formed. The length of bund per hectare area of land is given as:

L= 10000/H.I

= (10000*S)/(VI*100)

$$= 100(S/VI) \qquad (6.9)$$

8.4.5. Earth Work: The earth work of bunding system includes the sum of earthwork made in main bunds, side bunds and lateral bunds formed in the field. The earthwork of any bund is obtained by multiplying the cross-sectional area to its total length. The total earthwork can be given by the following equation.

$$E_t = E_m + E_s + E_l \qquad (6.10)$$

where, E_t = total earthwork, E_m = earthwork of main bunds, E_s = earthwork of side bunds, E_l = earthwork of lateral bunds, E_m = cross-sectional area * total length of bund = (100S/VI)* cross-sectional area.

Therefore, $E_s + E_l$ = ((100S/VI) * 30/100) * cross-sectional area

Therefore, total $E_t = E_m + E_s + E_t$

= (100S/VI + 30S/VI)* cross-sectional area

= 130S/VI * cross-sectional area

E_t = 1.3 * (100S/VI) * cross-sectional area of bund

In the above calculation the value of $E_s + E_l$ is taken as 30% earth work of main contour bund (E_m) by assuming that the length of side and lateral bund to be as 30% of the length of main bund and their cross-sectional area is also equal to main bund.

8.4.6. Area Lost due to Bunding: It is calculated by multiplying the length of contour bund per hectare with its base width. i.e

$$A_L = 10000/HI * b$$

$$= 100S/VI * b$$

Where, b is the base width of bund.

This equation computes only the area lost due to main contour bund and not the area lost due to side and lateral bunds. Usually, the area lost due to side and lateral bunds is taken as 30% of the area lost due to main contour bund. Thus, the total area lost due to contour bunding is:

$$\left(\left(\frac{100S}{VI}\right) * b + \left(\frac{100S}{VI}\right) * b * \frac{30}{100}\right)$$

$$= 1.3 * \frac{100S}{VI} * b$$

The above equation can also be written in the following form to compute the area lost in percentage due to bunding:

$$A_L\,(\%) = 1.3*S*b/VI$$

8.4.7 Construction of Bunds

Construction of bunds should start from the ridge and continue down the valley. This will ensure protection of the bunds if rains occur during construction. The base width area of the bund should be cleared of vegetation and the soil in this area should also be slightly distributed so that good binding can be achieved when the bund is formed over it. The burrow pits for the soil are generally located on the upstream side of the bund. It should have a uniform depth of 30 cm and the width can be varied as per necessity. The burrow pits should be continuous and no breaks are to be left. The burrow pits should not be located in a gully or depression. When the soil is dug, the clods should not be put on the bund at a time. The earth should be put in layers of 15 cm and consolidated by trampling. The templates of the specified dimensions are used for checking the bund section. The bund section should be finally shaped, trimmed and slightly rammed on the top and the sides. After the bund formation, it is desirable to plough the field and the burrow pit.

A Terrace is an earth-embankment, constructed across the slope, to control runoff and minimize soil erosion. A terrace acts as an intercept to land slope, and divides the sloping land surface into strips. In limited widths of strips, the slope length naturally available for runoff is reduced. It has been found that soil loss is proportional to the square root of the length of slope; i.e. by shortening the length of run, soil erosion is reduced. The soil eroded by the runoff scour and the raindrop splash flows down the slope, and gets blocked up by terraces. The scour of soil surface because of runoff water is initiated by the runoff at a velocity above the critical value, attained during a flow on long length of the sloping run. Thus, by shortening the length of run, the runoff velocity remains less than the critical value and therefore soil erosion owing to scour is prevented.

Terraces are classified into to two major types: broad-base terraces and bench terraces. Broad-base terraces are adapted where the main purpose is either to remove or retain water on sloping land suitable for cultivation whereas, the purpose of bench terraces is mainly to reduce the land slope. The classification of the terraces is given in Fig. 8.1.

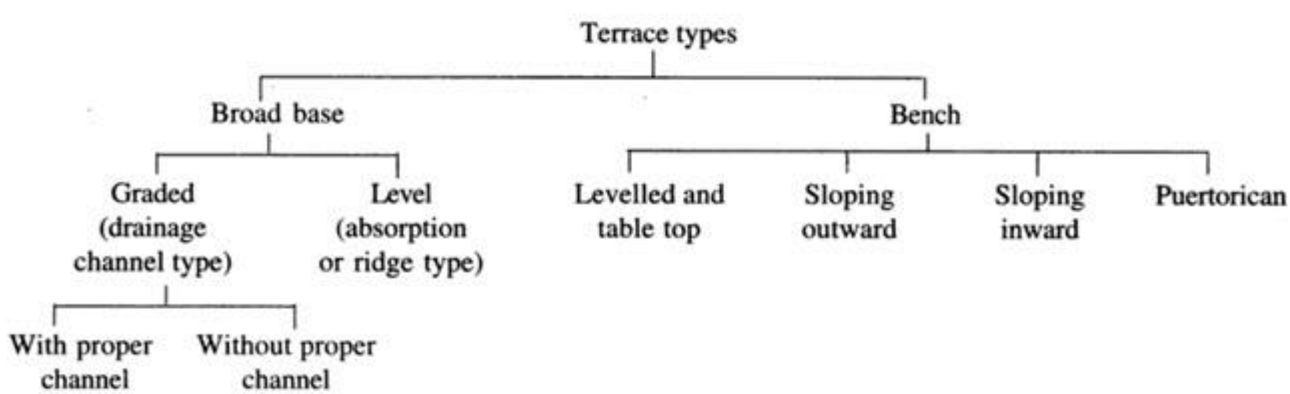

Fig. 8.1. Types of terraces.

8.5 Bench Terracing

The original bench terrace system consists of a series of flat shelf-like areas that convert a steep slope of 20 to 30 percent to a series of level, or nearly level benches (Fig. 8.2). In other words, bench terracing consists of construction of series of platforms along contours cut into hill slope in a step like formation. These platforms are separated at regular intervals by vertical drop or by steep sided and protected by vegetation and sometimes packed by stone retaining walls. In fact, bench terrace converts the long un-interrupted slope into several small strips and make protected platform available for farming. In several hilly areas bench terraces have been used for the purpose of converting hill slopes to suit agriculture. In some areas where the climatic conditions favour the growing of certain cash crops like potato, coffee etc., the hill slopes are to be bench terraced before the area is put for cultivation of these crops. Bench terraces have also been adopted for converting sloping lands into irrigated fields or for orchard plantations.

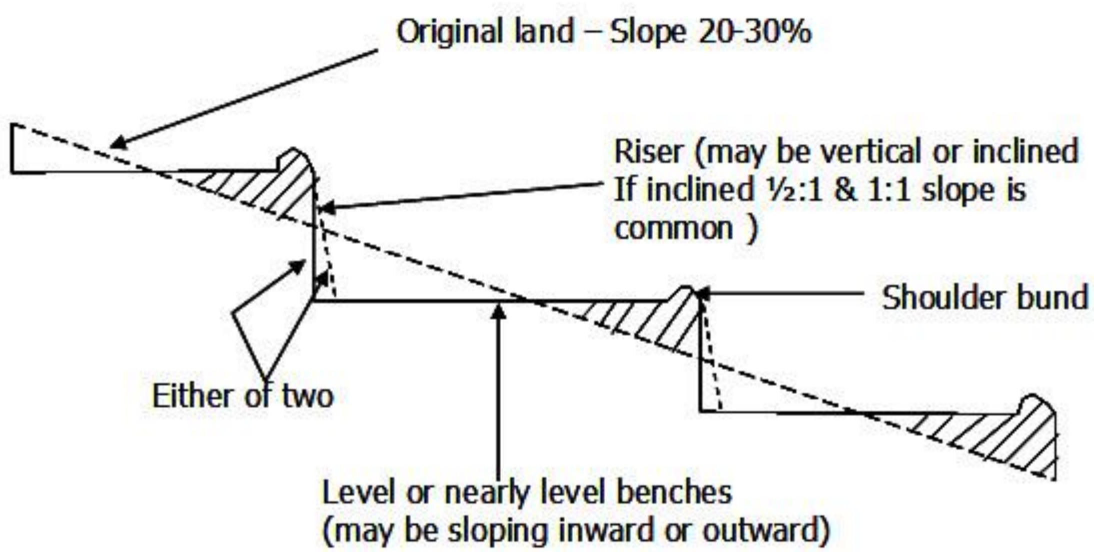

Fig. 8.2. Bench terrace and its different components.

8.5.1 Types of Bench Terraces

Depending on the purpose for which they are used, bench terraces are also classified as follows:

1. Hill-type bench terraces: used for hilly areas with a grade reversely towards the hill.

2. Irrigated bench terraces: level benches adopted under irrigated conditions.

3. Orchard bench terraces: narrow width terraces for individual trees. These are also referred to as intermittent terraces and step terraces.

The conversion of land into bench terraces over a period of time is referred to as gradual bench terracing. Bench terraces are classified depending upon the slope of benches. The different types are: (i) bench terraces sloping outward; (ii) bench terraces sloping inward and (iii) bench terraces with level top.

Bench terraces with slopes inside are to be adopted in heavy rainfall areas where a major portion of the rainfall is to be drained as surface runoff. In the case of these terraces, a suitable drain at the inward end of each of these terraces is to be provided to drain the runoff. These drains ultimately lead to a suitable outlet. These are also known as hill-type terraces. Bench terraces with level top are suitable for areas of medium rainfall, evenly distributed and having deep and highly permeable soils. Due to the fact that no slope is given to the benches it is expected that the most of the rainfall coming over the area is to be absorbed by the soil and very little water is to go as surface drainage. These types of terraces are also used where irrigation facilities are available and referred to as irrigated bench terraces. Bench terraces sloping outward are to be used in low rainfall areas with permeable soils. For bench terraces sloping outward a shoulder bund is essential even though such a bund is provided in the other two types also for giving stability to the edge of the terrace. In these terraces the rainfall thus conserved will have more time for soaking into the soil. Bench terraces with narrow width (about 1 m) are sometimes constructed for orchards bench terraces. These terraces are referred to as step terraces when a series of step like formations are made.

8.5.2 Design of Bench Terraces

For the designing of the bench terraces for a particular tract the average rainfall, the soil type, soil depth and the average slope of the area should be known. In addition the purpose for which the terraces are to be constructed should also be known. The design of bench terraces consists of determining the (1) type of the bench terrace, (2) terrace spacing or the depth of the cut, (3) terrace width, and (4) terrace cross section. Selection of the type of bench terrace among the three types, described earlier, depends upon the rainfall and soil conditions.

Terrace spacing is generally expressed as the vertical interval between two terraces. The vertical interval (D) is dependent upon the depth of the cut and since the cut and fill are to be balanced, it is equal to double the depth of cut. The factors that limit the depth of cut are the soil depth in the area and the slope. The depth of cut should not be too high as to expose the bed rock which makes the bench terraces unsuitable for cultivation. In higher slopes greater depth of cuts result in greater heights of embankments which may become unstable.

The width of the bench terraces (W) should be as per the requirement (purpose) for which the terraces are to be put after construction. Once the width of the terrace is decided, the depth of cut required can be calculated using the following formulae.

Case 1: When the terrace cuts are vertical

$$D = \frac{WS}{100} \tag{8.1}$$

S is the land slope in percent; D/2 is the depth of cut and W is the width of terrace.

Case 2: When the batter slope is 1:1

$$\frac{D/2}{W/2 + D/2} = \frac{S}{100}$$

$$D = \frac{WS}{(100 - S)} \tag{8.2}$$

Case 3: When the batter slope is ½: 1

$$\frac{D/2}{W/2 + D/4} = \frac{S}{100}$$

$$D = \frac{2WS}{(200 - S)} \tag{8.3}$$

After deciding the required width, the depth of cut can be calculated from one of the above formulae.

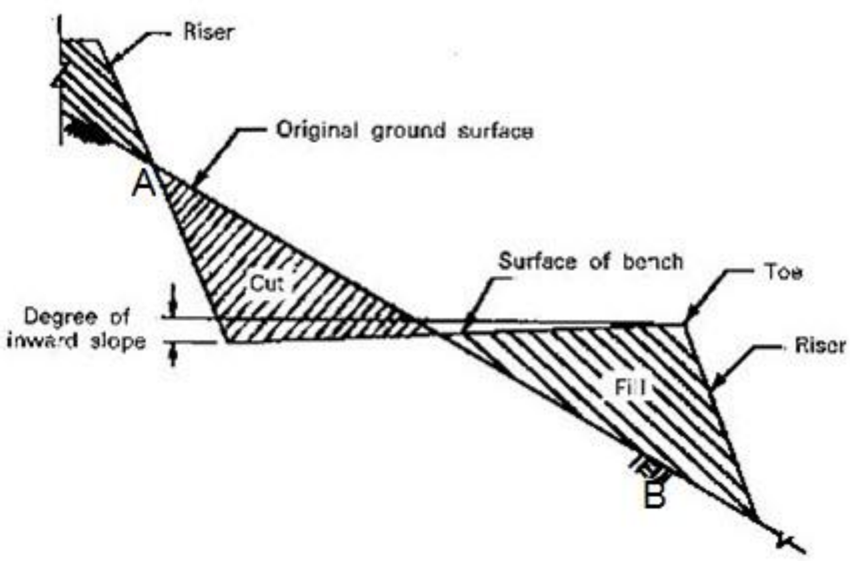

Fig: 8.3 Cross section of bench terraces.

The design of the terrace cross section consists of deciding (1) the batter slope, (2) dimensions of the shoulder bund, (3) inward slope of the terrace and the dimensions of the drainage channel in case of terraces sloping inward, and (4) outward slope in case of terraces sloping outward (Fig. 8.3). The batter slope is mainly for the stability of the fill or the embankment. The flatter the batter slope, the larger the area lost due to bench terracing. Vertical cuts are to be used in very stable soils and when the depth of the cut is small (up to 1 m). Batter slopes of ½: 1 can be used in loose and unstable soils. The size of the shoulder bunds in case of terraces sloping inward is nominal. In case of terraces with flat top and sloping outwards, larger sections of shoulder bunds are required as water stands against these bunds. The bund cross section depends upon the terrace width and soil conditions. The inward slope of the terrace may be from 1 in 50 to 1 in 10 depending upon the soil conditions. For these terraces a drainage channel is to be provided at the inner edge of the terrace to dispose of the runoff.

8.5.3 Alignment of Bench Terraces

Alignment of bench terraces should start from the ridge and progress towards the valley. The average land slope of the area to be terraced should be determined by taking levels and then the specifications of the terrace should be worked out. Contour lines may be marked with the help of a leveling instrument. Taking a contour line as the centre line, the terrace width may be marked on the ground. The alignment may now be examined and suitable adjustments should be made wherever necessary taking into considerations the local conditions like depressions, sharp turns, field boundaries etc. that exist at the site.

Construction of the bench terraces may be started from the highest terrace and proceeded downwards. By this method, the top soil and the subsoil get mixed up and the top soil may not be available for the terrace surface. In cases where the subsoil condition is not good, it is necessary to keep the top soil apart and again spread it on the terrace. This can be accomplished by starting the construction of the terraces from the lower most one. After the construction of the first terrace, the top soil from the second terrace may be spread on the first terrace and the process continued for subsequent terraces. In bench terraced areas, suitable outlets should be provided to dispose of the runoff safely. In most of the cases one of the sides of the hill slope where vegetation is well established can be used as the outlet. Where such outlets are not available or feasible, waterways are to be formed to dispose of the runoff.

8.5.4 Area Lost for Cultivation due to Bench Terracing

The area lost for cultivation due to bench terracing of a slope can be calculated as follows.

Consider a batter slope of 1:1. Let D be the vertical interval of the benches to be laid out on a land with a slope of S %, along AB in Fig. 5.3 and the batter of the risers is 1:1. L is the horizontal interval between the benches i.e., projected length of AB on horizontal plane. Actual distance of AB is given by:

$$AB = \sqrt{L^2 + D^2} \qquad (8.4)$$

$$= L\left[1 + \frac{D^2}{2L^2} + \frac{D^4}{8L^4} + \ldots\ldots\right]$$

$$AB = L + \frac{D^2}{2L} \qquad (8.5)$$

$$L = \frac{100D}{S}$$

$$AB = \frac{100D}{S} + \frac{D^2}{2} \cdot \frac{S}{100D}$$

$$= \frac{100D}{S} + \frac{DS}{200}$$

If W is the width available for cultivation after terracing:

$$W + D = L = \frac{100D}{S} \qquad (8.6)$$

$$W = \frac{100D}{S} - D = \frac{100D - DS}{S}$$

Width not available for cultivation after terracing (from equations 8.5 and 8.6)

$$= AB - W$$

$$= \frac{100D}{S} + \frac{DS}{200} - \frac{100D}{S} + \frac{DS}{S}$$

$$= \frac{DS}{200} + \frac{DS}{S}$$

Width loss in percentage of original inclined width AB

$$= \frac{\frac{DS}{200} + \frac{DS}{S}}{\frac{100D}{S} + \frac{DS}{200}} * 100$$

$$= \frac{\frac{S}{200} + 1}{\frac{100}{s} + \frac{S}{200}} * 100 = \frac{(S+200)S}{20000 + S^2} * 100$$

By dividing the numerator and the denominator by 100 width lost in percentage of the original width

$$= \frac{S+200}{\frac{200}{S} + \frac{S}{100}}$$

The percentage width lost can be taken as the percentage area lost. When the batter is vertical, the length of bench terrace per hectare in metres will be 10000/W where W is in metres. When the batter slope is 1:1 the length per hectare in metres will be 10000/W + D; D and W being in meters.

8.5.5 Maintenance of Bench Terraces

New terraces should be protected at their risers and outlets and should be carefully maintained, especially during the first two years. After cutting a terrace, its riser should be shaped and planted with grass as soon as possible. Sod-forming or rhizome-type grasses are better than those of the tall or bunch-type. Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers. An additional protection method is hydro-seeding. The outlet for drainage-type terraces is the point where the run-off leaves the terrace and goes into the waterway. Its gradient is usually steep and should be protected by sods of earth. A piece of rock, a brick, or a cement block, is sometimes needed to check the water flow on steeper channels. Similar checks on water flow are required for level bench terraces where the water falls from the higher terraces onto those below. A piece of rock should be placed on the lower terrace to dissipate the energy of the flowing water. The shoulder bund should be planted with permanent vegetation and ploughing of the toe of bund should be avoided. The batter slope of the terraces should be stabilized and protected by establishing deep rooted and soil binding spreading type of grasses.

8.5.5.1 Benches

The toe drains should be always open and properly graded; water must not be allowed to accumulate in any part of the terrace. All runoff should be allowed to collect at the toe drains for safe disposal to the protected waterway. Obstacles such as continuous mounds or beds must be removed at regular intervals to allow water to pass to the toe drain. Grasses and weeds should be removed from the benches. Correct gradients should be maintained and reshaped immediately after crops are harvested. Ploughing must be carried out with care so as not to destroy the toe drains and the grade.

8.5.5.2 Risers

Grasses should be grown well on the risers. Weeds and vines which threaten the survival of the grasses should be cut down or uprooted. Grasses should not be allowed to grow too high. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or graze the grasses. Runoff should not be allowed to flow over the risers on reverse-sloped terraces.

8.5.5.3 Outlets for Drainage Types of Terrace

The outlets should be checked to see whether they are adequately protected. Make sure that the water flows through the outlets instead of going around them. Any breaks must be mended immediately.

8.5.5.4 Soil Productivity

Deep ploughing, ripping or sub-soiling is needed to improve the structure of the soils on the cut part of the bench terraces. Green manuring, compost or sludge is needed in the initial period in order to increase soil fertility. Soil productivity should be maintained by means of proper crop rotation and the use of fertilizers.

09	Grassed water ways and their design.

Grassed waterways are natural or man made constructed channels established for the transport of concentrated flow at safe velocities from the catchment using adequate erosion resistant vegetation which cover the channels. These channels are used for the safe disposal of excess runoff from the crop lands to some safe outlet, namely rivers, reservoirs, streams etc. without causing soil erosion. Terraced and bunded crop lands, diversion channels, spillways, contour furrows, etc. from which excess runoff is to be disposed of, preferably use constructed grassed waterways for safe disposal of the runoff. The grassed waterways outlets are constructed prior to the construction of terraces, bunds etc. because grasses take time to get established on the channel bed. Generally, it is recommended that there should be a gap of one year so that the grasses can be established during the rainy season.

9.1 Purpose of Grassed Waterways

Grassed waterways are used as outlets to prevent rill and gully formation. The vegetative cover slows the water flow, minimizing channel surface erosion. When properly constructed, grassed waterways can safely transport large water flows to the down slope. These waterways can also be

used as outlets for water released from contoured and terraced systems and from diverted channels. This best management practice can reduce sedimentation of nearby water bodies and pollutants in runoff. The vegetation improves the soil aeration and water quality (impacting the aquatic habitat) due to its nutrient removal (nitrogen, phosphorus, herbicides and pesticides) through plant uptake and sorption by soil. The waterways can also provide a wildlife habitat.

9.2 Design of Grassed Waterways

The designs of the grassed waterways are similar to the design of the irrigation channels and are designed based on their functional requirements. Generally, these waterways are designed for carrying the maximum runoff for a 10- year recurrence interval period. The rational formula is invariably used to determine the peak runoff rate. Waterways can be shorter in length or sometimes, can be even very long. For shorter lengths, the estimated flow at the waterways outlets forms the design criterion, and for longer lengths, a variable capacity waterway is designed to account for the changing drainage areas.

9.2.1 Size of Waterway

The size of the waterway depends upon the expected runoff. A 10 year recurrence interval is used to calculate the maximum expected runoff to the waterway. As the catchment area of the waterway increases towards the outlet, the expected runoff is calculated for different reaches of the waterway and used for design purposes. The waterway is to be given greater cross-sectional area towards the outlet as the amount of water gradually increases towards the outlet. The cross-sectional area is calculated using the following formula:

$$a = Q/V \qquad (9.1)$$

where, a = cross-sectional area of the channel,

Q = expected maximum runoff, and

V = velocity of flow.

9.2.2 Shape of Water Way

The shape of the waterway depends upon the field conditions and type of the construction equipment used. The three common shapes adopted are trapezoidal, triangular, and parabolic shapes. In course of time due to flow of water and sediment depositions, the waterways assume an irregular shape nearing the parabolic shape. If the farm machinery has to cross the waterways, parabolic shape or trapezoidal shape with very flat side slopes are preferred. The geometric characteristics of different waterways are shown in Fig. 9.1 and Fig. 9.2 for trapezoidal and parabolic waterways respectively.

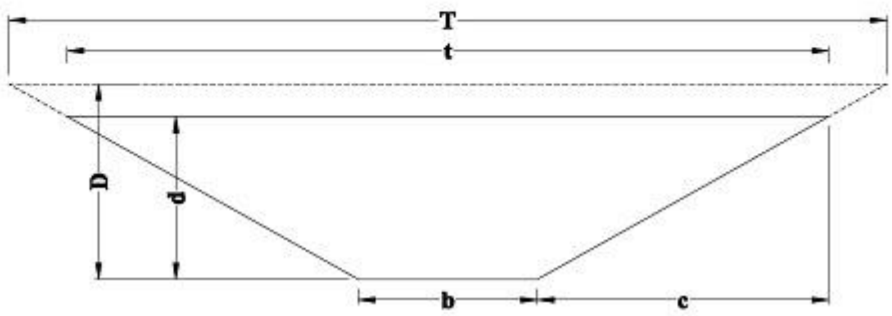

Fig. 9.1. Trapezoidal Cross-section. (Source: Murty, 2009)

In the figure, d is the depth of water flow, b is bottom width, t is the top width of maximum water conveyance, T is top width after considering free board depth, (D - d) is the free board and slope (z) is c/d.

The design dimensions for trapezoidal and parabolic waterways are given in Tables 9.1 and 9.2 respectively.

Table 9.1. Design Dimensions for Trapezoidal Cross-section

Cross-sectional Area, a	Wetted perimeter, P	Hydraulic Radius, $R = \frac{a}{p}$	Top width
$bd + zd^2$ Where, Z = c/d	$b + 2d\sqrt{Z^2 + 1}$	$\frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}}$	T = b + 2dz T = b + 2Dz

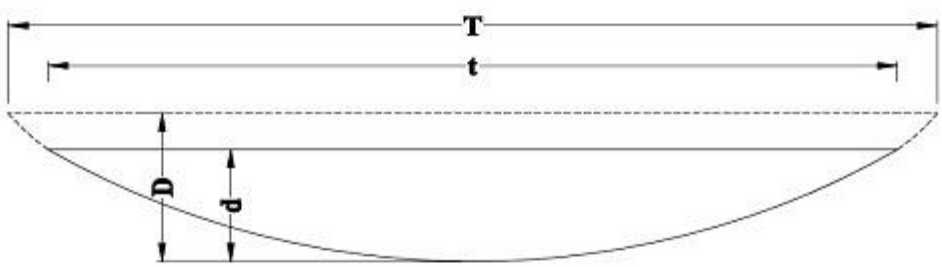

Fig. 9.2. Parabolic Cross-section. (Source: Murty, 2009)

Table 9.2. Design Dimensions for Parabolic Cross-Section

Cross-sectional Area, a	Wetted perimeter, P	Hydraulic Radius, $R = \frac{a}{p}$	Top width
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2 \times d}{1.5t^2 + 4d^2}$ $\frac{2d}{3} approx$	$t = \frac{a}{0.67d}$ $T = t\left(\frac{D}{d}\right)^{\frac{1}{2}}$

9.2.3 Channel Flow Velocity

The velocity of flow in a grassed waterway is dependent on the condition of the vegetation and the soil erodibility. It is recommended to have a uniform cover of vegetation over the channel surface to ensure channel stability and smooth flow. The velocity of flow through the grassed waterway depends upon the ability of the vegetation in the channel to resist erosion. Even though different types of grasses have different capabilities to resist erosion; an average of 1.0 m/sec to 2.5 m/sec are the average velocities used for design purposes. It may be noted that the average velocity of flow is higher than the actual velocity in contact with the bed of the channel. Velocity distribution in a grassed lined channel is shown in Fig. 9.3. Recommended velocities of flow based on the type of vegetation are shown in Table 9.3. The permissible velocities of flow on different types of soils are given in table 9.4.

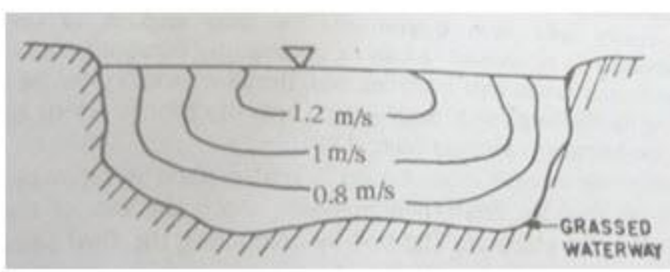

Fig. 9. 3. Velocity Distribution in Open Channel (Source: Murty, 2009)

Table 9.3. Recommend Velocities of Flow in a Vegetated Channel.

Type of vegetation cover	Flow velocity, (m/s)	
	Type	Magnitude
Spare green cover	Low velocity	1-1.15
Good quality cover	Medium velocity	1.5-1.8

Excellent quality cover	High velocity	1.8-2.5

Table 9.4. Permissible Velocity of Flow on Different Types of Soil. (Source: V.V.N. Murty)

Type of soil	Permissible velocity, (m/s)	
	Clean water	Colloidal water
Very fine sand	0.45	0.75
Sandy loam	0.55	0.75
Silty loam	0.60	0.90
Alluvial silt without colloids	0.60	1.00
Dense clay	0.75	1.00
Hard clay, colloidal	1.10	1.50
Very hard clay	1.80	1.80
Fine gravel	0.75	1.50
Medium and coarse gravel	1.20	1.80
Stones	1.50	1.80

9.2.4 Design of Cross-Section

The design of the cross-section is done using Equation 9.1 for finding the area required and Manning's formula is used for cross checking the velocity. A trial procedure is adopted. For required cross-sectional area, the dimensions of the channel section are assumed. Using hydraulic property of the assumed section, the average velocity of flow through the channel cross-section is calculated using the Manning's formula as below:

$$V = \frac{S^{1/2} R^{2/3}}{n} \qquad (9.2)$$

where, V = velocity of flow in m/s; S = energy slope in m/m; R = hydraulic mean radius of the section in m and n = Manning's roughness coefficient.

The Manning's roughness coefficient is to be selected depending on the existing and proposed vegetation to be established in the bed of the channel. Velocity is not an independent parameter. It will depend on n which is already fixed according to vegetation, R which is a function of the channel geometry and slope S for uniform flow. Slope S has to be adjusted. If the existing land slope gives high velocity, alignment of the channel has to be changed to get the desired velocity.

Problem 9.1: Design a grassed waterway of parabolic shape to carry a flow of 2.6 m^3/s down a slope of 3 percent. The waterway has a good stand of grass and a velocity of 1.75 m/s can be allowed. Assume the value of *n* in Manning's formula as 0.04.

Solution: Using, Q = AV for a velocity of 1.75 m/s, a cross-section of 2.6/1.75 = 1.485 m^2 (~1.5 m^2) is needed.

Assuming, t = 4 m, d = 60 cm.

$$A = \frac{2}{3}t \times d = \frac{2}{3}4 \times 0.6 = 1.6m^2$$

$$P = t + 8\frac{d^2}{3t} = 4 + 8\frac{(0.6)^2}{3 \times 4} = 4.24m$$

$$R = \frac{A}{P} = \frac{1.6}{4.24} = 0.377m$$

$$V = \frac{S^{1/2}R^{2/3}}{n} = \frac{(0.03)^{1/2} \times (0.377)^{2/3}}{0.04} = 2.26m/s$$

The velocity exceeds the permissible limit. Assuming a revised

t = 6 m and d = 0.4 m

$$A = \frac{2}{3}t \times d = \frac{2}{3}4 \times 0.6 = 1.6m^2$$

$$P = t + 8\frac{d^2}{3t} = 6 + 8\frac{(0.4)^2}{3 \times 6} = 6.45m$$

$$V = \frac{S^{1/2}R^{2/3}}{n} = \frac{(0.03)^{1/2} \times (0.248)^{2/3}}{0.04} = 1.70m/s$$

The velocity is within the permissible limit.

Q = 1.6 × 1.7 = 2.72 m^3/s

The carrying capacity (Q) of the waterway is more than the required. Hence, the design of waterway is satisfactory. A suitable freeboard to the depth is to be provided in the final dimensions.

9.2.5 Construction of the Waterways

It is advantageous to construct the waterways at least one season before the bunding. It will give time for the grasses to get established in the waterways. First, unnecessary vegetation like shrubs etc. are removed from the area is marked for the waterways. The area is then ploughed if necessary and smoothened. Establishment of the grass is done either by seeding or sodding technique. Maintenance of the waterways is important for their proper operation. Removal of weeds, filling of the patches with grass and proper cutting of the grass are of the common maintenance operations that should be followed for an efficient use of waterways.

9.3 Selection of Suitable Grasses

The soil and climate conditions are the primary factors in selection of vegetations to be established for construction of grassed waterways. The other factors to be considered for selection of suitable grasses are duration of establishment, volume and velocity of runoff, ease of establishment and time required to develop a good vegetative cover. Furthermore, the suitability of the vegetation for utilization as feed or hay, spreading of vegetation to the adjoining fields, cost and availability of seeds and redundancy to shallow flows in relation to the sedimentation are the important factors that should be considered for the selection of vegetation.

Generally, the rhizomatous grasses are preferred for the waterway, because they get spread very quickly and provide more protection to the channel than the brush grasses. Deep rooted legumes are seldom used for grassed waterways, because they have the tendency to loosen the soil and thus make the soil more erodible under the effect of fast flowing runoff water. Sometimes, a light seeding of small grain is also used to develop a quick cover before the grasses are fully established in the waterway.

9.4 Construction Procedure and Maintenance

Ordinary tools such as slip scraper can be easily used for construction of waterways. However, the use of grader blade or a bulldozer can be preferred, particularly when a considerable earth movement is needed. Since the channel is prone to erosion before vegetations are established, it is very essential to construct the waterway when the field is in meadow and the amount of runoff from the area is also very less. In addition, if the erosion hazard is very high, then runoff should also be essentially diverted from the waterway until a good grassed cover is developed in the waterway.

The construction of grassed waterways is carried out using the following steps.

Step-1: Shaping (Soil Digging)

The shaping of the waterway should be done as straight and even as possible. Any sudden fall or sharp turn must be eliminated, except in the area where the structure is planned to be installed in the waterway. In addition, the grade should also be shaped according to the designed plan. Also, the stones and stumps which are likely to interfere with the discharge rate must be removed.

Step-2: Grass Planting

After shaping the waterway channel, the planting of grasses is very important. Priorities should always be given to the local species of grasses. The short forming or rhizome grasses are more preferable as compared to the tall bunch type grasses.

In large waterways, the seeding is cheaper than the sodding. Therefore, the seeding should be preferred for grass development. It is also suggested that the seeded area should be mulched especially for production purposes. Immediately after grass planting, the waterways should not be allowed for runoff flow.

Step 3: Ballasting

Ballasting is done in those localities where rocks are readily available adjacent to the sites and waterway gradient is very steep. Ballasting is generally recommended for the waterways in the small farms. The stones to be used for this purpose should be at least of 15 to 20 cm diameter; and they should be placed firmly on the ground. From stability point of view, on very steep slopes, wire mesh should be used to encase the stones. In parabolic shaped waterways, partial ballasting should be done in the centre, leaving the sides with grass protection.

Step 4: Placing of Structure

Structures (drop) are essential if there is sudden fall in the waterway flow path. Because under this situation, there is a possibility of soil scouring due to falling of water flow from a higher elevation to a lower elevation. For eliminating this problem, the constructed structure must be sufficiently strong to handle the designed flows successfully. As a precautionary measure, care should be taken to see that the water must not flow from the below or around the structure but through the top of the structure. In addition, the structure should be constructed on firm soils with strong and deep foundation. The apron or stilling basin of drop structures should be sufficiently strong and able to absorb or dissipate the energy/impact of falling water. After construction, earth filling should be done around the structure and it should be properly consolidated to prevent further settlement. Proper sodding should also be provided at the junction of earth filling and the structure to prevent tunneling.

9.4.1 Maintenance

The grasses grown in waterway should always be kept short and flexible, so that they shingle as water flows over them, but do not lodge permanently. For this purpose, the grass should be mowed two to three times in a year. The mowed grasses must be removed from the waterway, so that they do not get accumulated at some spots in the waterway and also should not obstruct the flow. The deposition of mowed grasses in the section of the waterway reduces the flow capacity of the waterway and also diverts the direction of flowing water which can cause turbulence and thus damage of the channel. It is also possible to keep the grasses short by light pasturing, which should not be done in wet condition. When the grass is pastured, it is necessary to apply manure to discourage grazing. The waterway should not be used as a road for livestock. After the vegetative cover is established and runoff passes through them for a long time, a light application of fertilizer should be done because the flowing runoff removes the plant food from the soil of waterway.

Similarly, if waterways are to be crossed by tillage implements, they should be disengaged, plough should be lifted and disc straightened. Tillage operation should also be done following nearly the contour. The waterway and its sides should not be touched during tillage operation. It is also essential that if there is any damage of the waterway, it should be quickly repaired so that the damage may not enlarge due to rainfalls. Overall, it should always be remembered that the waterways are an integral part of watershed conservation or land treatment system. If they fail to handle the peak discharge due to lack of proper maintenance, then the prolong flow of runoff through them can develop gullies in the area. Briefly, the maintenance of waterways can be taken up using the following process.

a) The outlets should be safe and open so as not to impede the free flow.

b) Grassed waterways should not be used as footpaths, animal tracks, or as grazing grounds.

c) Frequent crossing of waterways by wheeled vehicles should not be allowed.

d) Newly established waterways should be kept under strict watch.

e) The large waterways should be kept under protection with fencing.

f) Waterways must be inspected frequently during first two rainy seasons, after construction.

g) If there is any break in the channel or structures, then they should be repaired immediately.

h) The bushes or large plants grown in the waterway should be removed immediately as they may endanger the growth of grasses.

i) The level of grass in waterway should be kept as low and uniform as possible to avoid turbulent flow.

10	Water harvesting and its techniques.

10.1 Importance of Water Harvesting

Rainwater harvesting, in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall. It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system. It is also a good option in areas where good quality fresh surface water or ground water is lacking. Water harvesting enables efficient collection and storage of rainwater, makes it accessible and substitute for poor quality water. There are a number of ways by which water harvesting can benefit a community.

- Improvement in the quality of ground water,
- Rise in the water levels in wells and bore wells that are drying up,
- Mitigation of the effects of drought and attainment of drought proofing,
- An ideal solution in areas having inadequate water resources,
- Reduction in the soil erosion as the surface runoff is reduced,
- Decrease in the choking of storm water drains and flooding of roads and
- Saving of energy to lift ground water.

10.2 Types of Water Harvesting

Rainwater Harvesting: Rainwater harvesting is defined as the method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Three types of water harvesting are covered by rainwater harvesting.

- Water collected from roof tops, courtyards and similar compacted or treated surfaces is used for domestic purpose or garden crops.
- Micro-catchment water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a tree, a bush or with annual crops.
- Macro-catchment water harvesting, also called harvesting from external catchments is the case where runoff from hill-slope catchments is conveyed to the cropping area located at foothill on flat terrain.

Flood Water Harvesting: Flood water harvesting can be defined as the collection and storage of creek flow for irrigation use. Flood water harvesting, also known as 'large catchment water harvesting' or 'Spate Irrigation', may be classified into following two forms:

- In case of 'flood water harvesting within stream bed', the water flow is dammed and as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
- In case of 'flood water diversion', the wadi water is forced to leave its natural course and conveyed to nearby cropping fields.

Groundwater Harvesting: Groundwater harvesting is a rather new term and employed to cover traditional as well as unconventional ways of ground water extraction. Qanat systems, underground dams and special types of wells are a few examples of the groundwater harvesting techniques. Groundwater dams like 'Subsurface Dams' and 'Sand Storage Dams' are other fine examples of groundwater harvesting. They obstruct the flow of ephemeral streams in a river bed; the water is stored in the sediment below ground surface and can be used for aquifer recharge.

10.3 Water Harvesting Technique

This includes runoff harvesting, flood water harvesting and groundwater harvesting.

10.3.1 Runoff Harvesting

Runoff harvesting for short and long term is done by constructing structures as given below.

10.3.1.1 Short Term Runoff Harvesting Techniques

Contour Bunds: This method involves the construction of bunds on the contour of the catchment area (Fig. 10.1). These bunds hold the flowing surface runoff in the area located between two adjacent bunds. The height of contour bund generally ranges from 0.30 to 1.0 m and length from 10 to a few 100 meters. The side slope of the bund should be as per the requirement. The height of the bund determines the storage capacity of its upstream area.

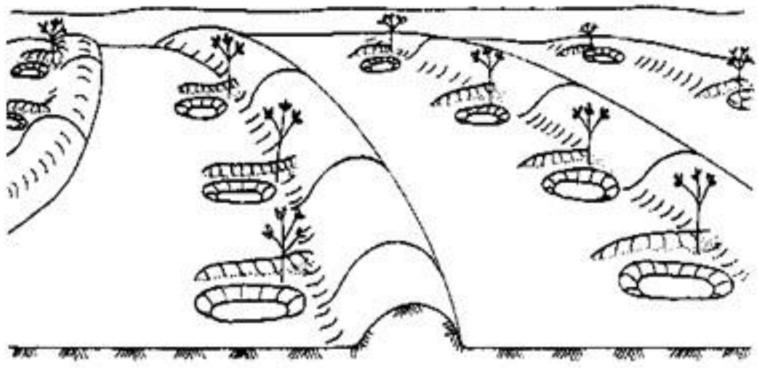

Fig. 10.1. Contour Bunds.

Semicircular Hoop: This type of structure consists of an earthen impartment constructed in the shape of a semicircle (Fig. 10.2). The tips of the semicircular hoop are furnished on the contour. The water contributed from the area is collected within the hoop to a maximum depth equal to the height of the embankment. Excess water is discharged from the point around the tips to the next lower hoop. The rows of semicircular hoops are arranged in a staggered form so that the over flowing water from the upper row can be easily interrupted by the lower row. The height of hoop is kept from 0.1 to 0.5 m and radius varies from 5 to 30 m. Such type of structure is mostly used for irrigation of grasses, fodder, shrubs, trees etc.

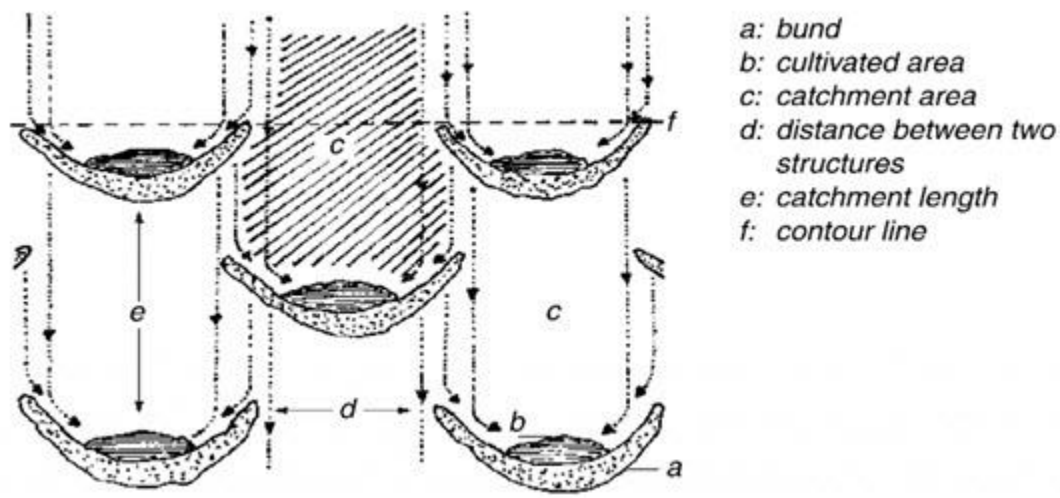

Fig. 10.2. Layout of Semi-Circular Hoop.

Trapezoidal Bunds: Such bunds also consist of an earthen embankment, constructed in the shape of trapezoids. The tips of the bund wings are placed on the contour. The runoff water yielded from the watershed is collected into the covered area. The excess water overflows around the tips. In this system of water harvesting the rows of bunds are also arranged in staggered form to intercept the overflow of water from the adjacent upstream areas. The layout of the trapezoidal bunds is the same as the semicircular hoops, but they unusually cover a larger area (Fig. 10.3).

Trapezoidal bund technique is suitable for the areas where the rainfall intensity is too high and causes large surface flow to damage the contour bunds. This technique of water harvesting is widely used for irrigating crops, grasses, shrubs, trees etc.

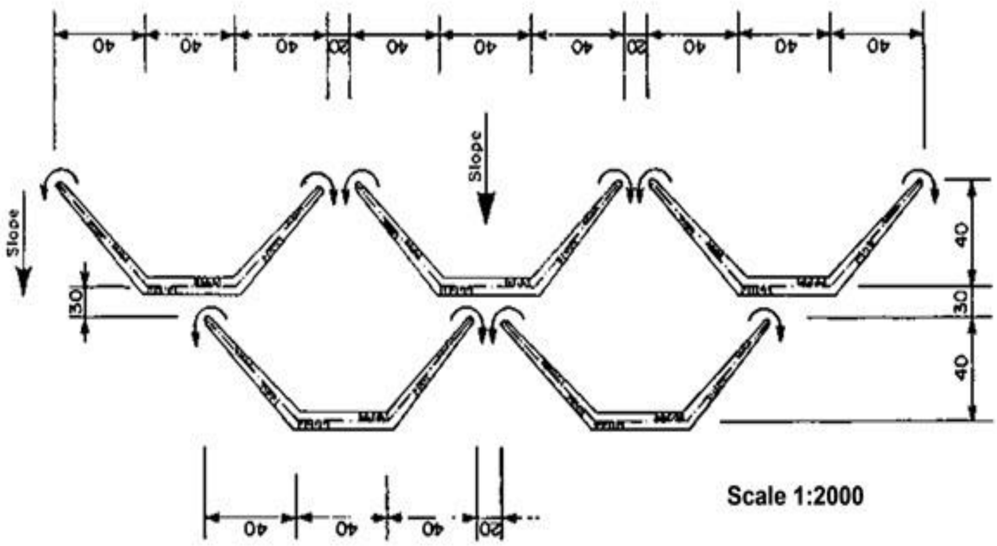

Fig. 10.3. Layout of Trapezoidal Bund.

Graded Bunds: Graded bunds also referred as off contour bunds. They consist of earthen or stone embankments and are constructed on a land with a slope range of 0.5 to 2%. The design and construction of graded bunds are different from the contour bunds. They are used as an option where rainfall intensity and soils are such that the runoff water discharged from the field can be easily intercepted. The excess intercepted or harvested water is diverted to the next field though a channel ranges. The height of the graded bund ranges from 0.3 to 0.6 m. The downstream bunds consist of wings to intercept the overflowing water from the upstream bunds. Due to this, the configuration of the graded bund looks like an open ended trapezoidal bund. That is why sometimes it is also known as modified trapezoidal bund. This type of bunds for water harvesting is generally used for irrigating the crops.

Rock Catchment: The rock catchments are the exposed rock surfaces, used for collecting the runoff water in a part as depressed area. The water harvesting under this method can be explained as: when rainfall occurs on the exposed rock surface, runoff takes place very rapidly because there is very little loss. The runoff so formed is drained towards the lowest point called storage tank and the harvested water is stored there. The area of rock catchment may vary from a 100 m^2 to few 1000 m^2; accordingly the dimensions of the storage tank should also be designed. The water collected in the tank can be used for domestic use or irrigation purposes.

Ground Catchment: In this method, a large area of ground is used as catchment for runoff yield. The runoff is diverted into a storage tank where it is stored. The ground is cleared from vegetation and compacted very well. The channels are as well compacted to reduce the seepage or percolation loss and sometimes they are also covered with gravel. Ground catchments are also called roaded catchments. This process is also called runoff inducement. Ground catchments

have also been traditionally used since last 4000 years in the Negev (a desert in southern Israel) where annul crops and some drought tolerant species like pistachio dependent on such harvested water are grown.

10.3.1.2 Long Term Runoff Harvesting Techniques

The long term runoff harvesting is done for building a large water storage for the purpose of irrigation, fish farming, electricity generation etc. It is done by constructing reservoirs and big ponds in the area. The design criteria of these constructions are given below.

- Watershed should contribute a sufficient amount of runoff.
- There should be suitable collection site, where water can be safely stored.
- Appropriate techniques should be used for minimizing various types of water losses such as seepage and evaporation during storage and its subsequent use in the watershed.
- There should also be some suitable methods for efficient utilization of the harvested water for maximizing crop yield per unit volume of available water.

The most common long term runoff harvesting structures are:

- Dugout Ponds
- Embankment Type Reservoirs

Dugout Ponds: The dugout ponds are constructed by excavating the soil from the ground surface. These ponds may be fed by ground water or surface runoff or by both. Construction of these ponds is limited to those areas which have land slope less than 4% and where water table lies within 1.5-2 meters depth from the ground surface (Fig. 10.4). Dugout ponds involve more construction cost, therefore these are generally recommended when embankment type ponds are not economically feasible. The dugout ponds can also be recommended where maximum utilization of the harvested runoff water is possible for increasing the production of some important crops. This type of ponds require brick lining with cement plastering to ensure maximum storage by reducing the seepage loss.

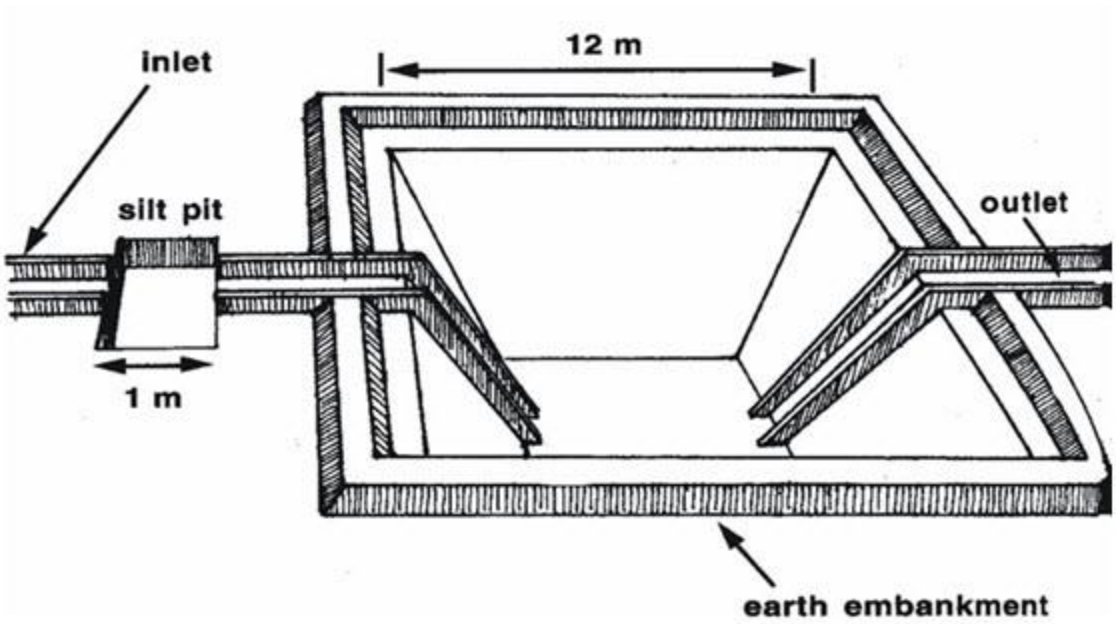

Fig. 10.4. Illustration of Dugout Pond.

Embankment Type Reservoir: These types of reservoirs are constructed by forming a dam or embankment on the valley or depression of the catchment area. The runoff water is collected into this reservoir and is used as per requirement. The storage capacity of the reservoir is determined on the basis of water requirement for various demands and available surface runoff from the catchment. In a situation when heavy uses of water are expected, then the storage capacity of the reservoir must be kept sufficient so that it can fulfill the demand for more than one year.

Embankment type reservoirs are again classified as given below according to the purpose for which they are meant.

Irrigation Dam: The irrigation dams are mainly meant to store the surface water for irrigating the crops. The capacity is decided based on the amount of input water available and output water desired. These dams have the provisions of gated pipe spillway for taking out the water from the reservoir. Spillway is located at the bottom of the dam leaving some minimum dead storage below it.

Silt Detention Dam: The basic purpose of silt detention dam is to detain the silt load coming along with the runoff water from the catchment area and simultaneously to harvest water. The silt laden water is stored in the depressed part of the catchment where the silt deposition takes place and comparatively silt free water is diverted for use. Such dams are located at the lower reaches of the catchment where water enters the valley and finally released into the streams. In this type of dam, provision of outlet is made for taking out the water for irrigation purposes. For better result a series of such dams can be constructed along the slope of the catchment.

High Level Pond: Such dams are located at the head of the valley to form the shape of a water tank or pond. The stored water in the pond is used to irrigate the area lying downstream. Usually, for better result a series of ponds can be constructed in such a way that the command area of the tank located upstream forms the catchment area for the downstream tank. Thus all but the uppermost tanks are facilitated with the collection of runoff and excess irrigation water from the adjacent higher catchment area.

Farm Pond: Farm ponds are constructed for multi-purpose objectives, such as for irrigation, live-stock, water supply to the cattle feed, fish production etc. The pond should have adequate capacity to meet all the requirements. The location of farm pond should be such that all requirements are easily and conveniently met.

Water Harvesting Pond: The farm ponds can be considered as water harvesting ponds. They may be dugout or embankment type. Their capacity depends upon the size of catchment area. Runoff yield from the catchment is diverted into these ponds, where it is properly stored. Measures against seepage and evaporation losses from these ponds should also be.

Percolation Dam: These dams are generally constructed at the valley head, without the provision of checking the percolation loss. Thus, a large portion of the runoff is stored in the soil. The growing crops on downstream side of the dam, receive the percolated water for their growth.

10.3.2 Flood Water Harvesting

To harvest flood water, wide valleys are reshaped and formed into a series of broad level terraces and the flood water is allowed to enter into them. The flood water is spread on these terraces where some amount of it is absorbed by the soil which is used later on by the crops grown in the area. Therefore, it is often referred to as "Water Spreading" and sometimes "Spate Irrigation". The main characteristics of water spreading are:

- Turbulent channel flow is harvested either (a) by diversion or (b) by spreading within the channel bed/valley floor.
- Runoff is stored in soil profile.
- It has usually a long catchment (may be several km)
- The ratio between catchment to cultivated area lies above 10:1.
- It has provision for overflow of excess water.

The typical examples of flood water harvesting through water spreading are given below.

Permeable Rock Dams (for Crops)

These are long low rock dams across valleys slowing and spreading floodwater as well as healing gullies (Fig. 10.5). These are suitable for a situation where gently sloping valleys are likely to transform into gullies and better water spreading is required.

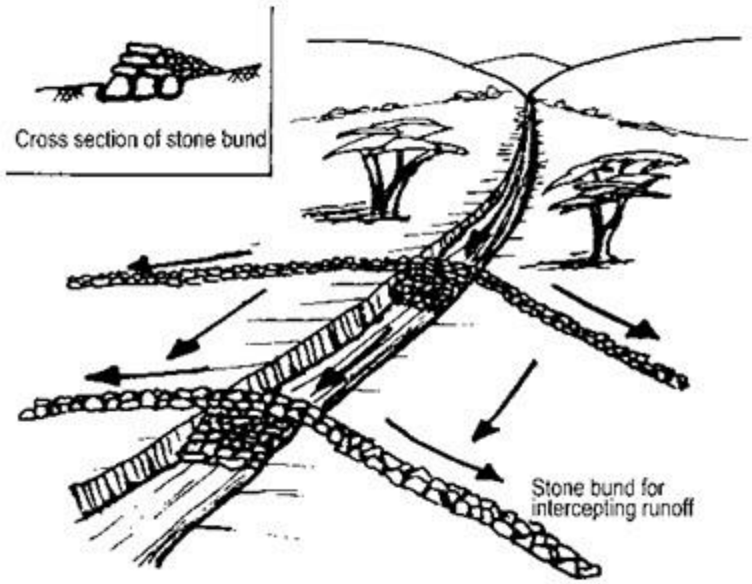

Fig. 10.5. Permeable Rock Dams

Water Spreading Bunds (for Crops and Rangeland): In this method, runoff water is diverted to the area covered by graded bund by constructing diversion structures such as diversion drains. They lead to the basin through channels, where crops are irrigated by flooding. Earthen bunds are set at a gradient, with a "dogleg" shape and helps in spreading diverted floodwater (Fig. 10.6). These are constructed in arid areas where water is diverted from watercourse onto crop or fodder block.

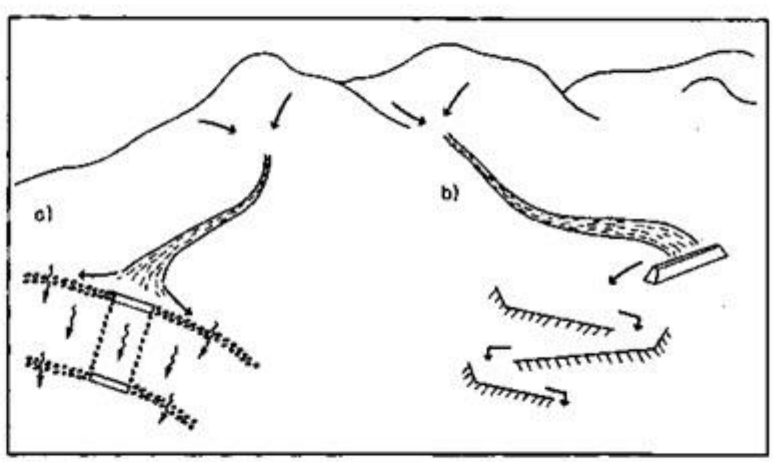

Fig. 10.6. Floodwater farming systems: (a) spreading within channel bed; (b) diversion system.

Flood Control Reservoir: The reservoirs constructed at suitable sites for controlling the flood are known as flood control reservoirs. They are well equipped with self-operating mechanical outlets for letting out the harvested water into the stream or canal below the reservoir as per requirement.

10.3.3 Groundwater Harvesting

Qanat System: A qanat consists of a long tunnel or conduit leading from a well dug at a reliable source of groundwater (the mother well). Often, the mother well is dug at the base of a hill or in the foothills of a mountain range. The tunnel leading from the mother well slopes gradually downward to communities in the valley below. Access shafts are dug intermittently along the horizontal conduit to allow for construction and maintenance of the qanat (Fig. 10.7). The Qanat system was used widely across Persia and the Middle East for many reasons. First, the system requires no energy, relies on the force of gravity alone. Second, the system can carry water across long distances through subterranean chambers avoiding leakage, evaporation, or pollution. And lastly, the discharge is fixed by nature, producing only the amount of water that is distributed naturally from a spring or mountain, ensuring that the water table is not depleted. More importantly, it allows access to a reliable and plentiful source of water to those living in otherwise marginal landscapes (Fig. 10.8).

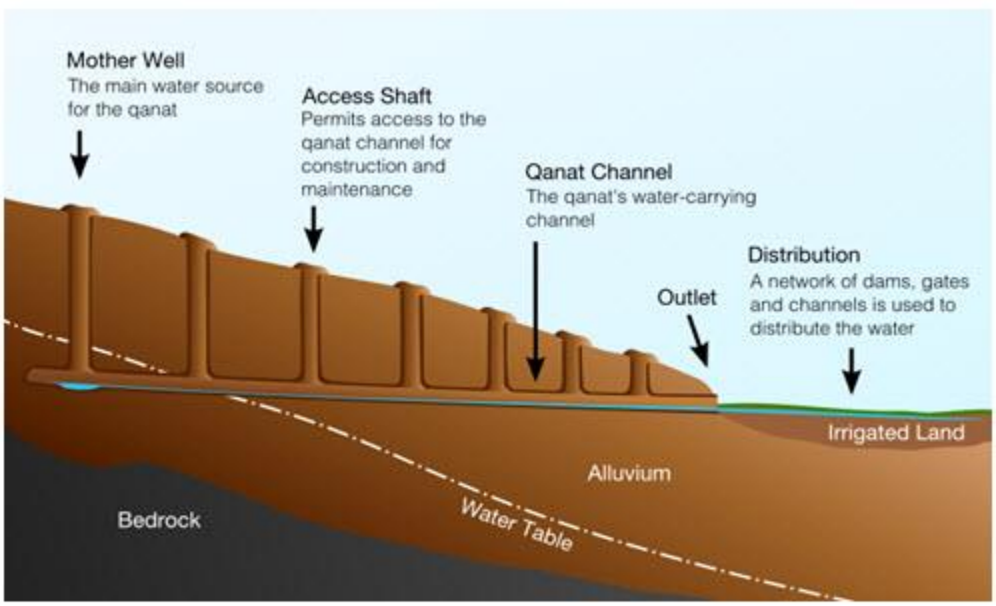

Fig. 10.7. Cross Section Showing Qanats.

Fig. 10.8. Ariel view of Qanats.

10.4 Runoff vs. Flood Water Harvesting

- Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term rainwater harvesting while all systems which collect discharges from watercourses are grouped under the term flood water harvesting.
- Runoff harvesting increases water availability for on-site vegetation while flood waters harvesting provide a valuable source of water to local and downstream water users and play an important role in replenishing floodplains, rivers, wetlands and groundwater.
- Runoff harvesting reduces water flow velocity, as well as erosion rate and controls siltation problem while in flood water harvesting**,** floodwater enters into the fields through the inundation canals, carrying not only rich silt but also fish which can swim through the canals into the lakes and tanks to feed on the larva of mosquitoes.

11	Wind erosion: mechanics of wind erosion, types of soil movement.

11.1 Wind Erosion

Wind erosion is a serious environmental problem. It is in no way less severe than water erosion. High velocity winds strike the bare lands (having no cover), with increasing force. Fine, loose and light soil particles blown from the land surface are taken miles and miles away and thereby, causing a great damage to the crop productivity. It is a common phenomenon occurring mostly in flat, bare areas; dry, sandy soils; or anywhere the soil is loose, dry and finely granulated and where high velocity wind blows. Wind erosion, in India, is commonly observed in arid and semi-arid areas where the precipitation is inadequate, e.g. Rajasthan and some parts of Gujarat, Punjab and Haryana.

Wind erosion damages land and natural vegetation by removing soil from one place and depositing it at another location. It causes soil loss, dryness and deterioration of soil structure, nutrient and productivity losses and air pollution. Smaller particles of soil are more subject to movement by wind as silt, clay and organic matter are removed from the surface soil by strong wind, leaving the coarse, lesser productive material behind. Suspended dust and dirt are inevitably deposited over everything. It blows on and inside homes, covers roads and highways, and smothers crops. Sediment transport and deposition are significant factors in the

geological changes which occur on the land around us and over long periods of time are important in the soil formation process. Most serious damage caused by wind erosion is the change in soil texture. Damage caused by wind erosion is demonstrated in Fig.11.1.

Fig. 11.1. An Illustration of Wind Erosion.

11.2 Factors Affecting Wind Erosion

Climate, soil and vegetation are the major factors affecting wind erosion at any particular location. The climatic factors that affect the wind erosion are the characteristics of wind itself (velocity and direction) in addition to the precipitation, humidity and temperature. Soil moisture conditions, texture, structure, density of particles, organic matter content are the soil characteristics that influence erosion by wind. Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of particles, and wind velocity itself. Surface features like vegetation or other artificial cover (mulching etc) have the protective effect on wind erosion problem as surface cover increases the roughness over the land surface and thus reduces the erosive wind force on the land surface.

11.3 Mechanics of Wind Erosion

The overall occurrence of wind erosion could be described in three distinct phases. These are:

1. Initiation of Movement

2. Transportation

3. Deposition.

Movement of soil particles is caused by wind forces exerted against or parallel to the ground surface. The erosive wind is turbulent at all heights except very close to the surface. The lowest velocity occurs close to the ground and increases in proportion to the logarithm of the height above the surface. Soil particles or other projections on the surface absorb most of the force exerted by the wind on the surface. However, if the soil particles are lighter and loose, wind may lift them from the surface in the initiation process. A minimum threshold velocity (wind) is required to initiate the movement of soil particles. Thus, the threshold velocity is the minimum wind velocity needed to initiate the movement of soil particles. The magnitude of the threshold velocity is not fixed for all places and conditions but it varies with the soil conditions and nature of the ground surface. For example, for the most erodible soils of particle size about 0.1 mm; the required threshold velocity is 16 km/h at a height of 30 cm above the ground.

11.3.1 Initiation of Movement: The soil particles are first detached from their place by the impact and cutting action of wind. These detached particles are then ready for movement by the wind forces. After this initiation of movement, soil particles are moved or transported by distinct mechanisms.

11.3.2 Transportation: The transportation of the soil particles are of three distinct types and occur depending upon size of the soil particles. Suspension, saltation, and surface creep are the three types of soil movement or transport which occur during wind erosion. While soil can be blown away at virtually any height, the majority (over 93%) of soil movement/transportation takes place at or within one meter height from land surface. These transportation mechanisms of soil particles due to wind are shown in Fig. 11.2.

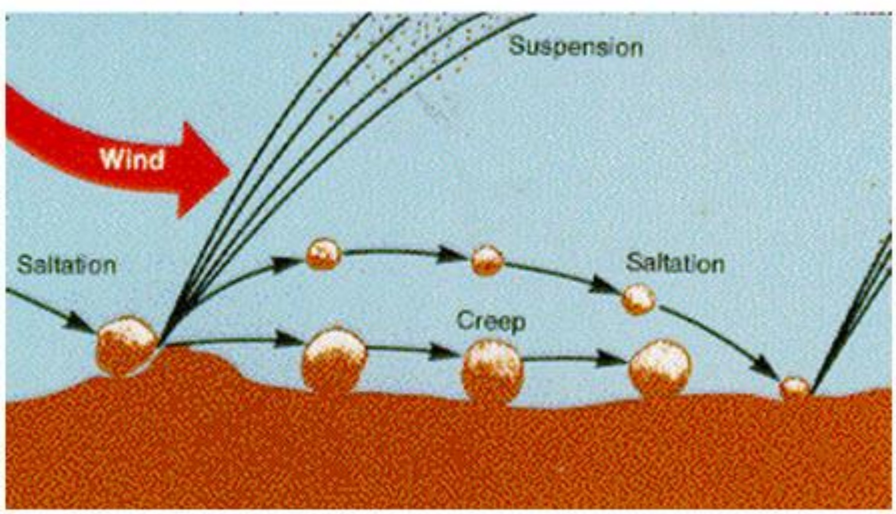

Fig. 11.2. Mechanics of Wind Erosion.

11.3.3 Suspension: It occurs when very fine dirt and dust particles are lifted into the atmosphere. They can be thrown into the air through impact with other particles or by the wind itself. These particles can be carried very high and be transported over very long distances in the atmosphere

by the winds. Soil moved by suspension is the most spectacular and easiest to recognize among the three forms of movement. The soil particles of less than 0.1 mm size are subjected to suspension and around 3 to 40 % of soil weights are carried by the suspension method of soil transport under the wind erosion.

11.3.4 Saltation: The major fraction of soil moved by the wind is through the process of saltation. Saltation movement is caused by the pressure of the wind on soil particles as well as by the collision of a particle with other particles. Soil particles (0.1 to 0.5 mm) move in a series of bounces and/or jumps. Fine soil particles are lifted into the air by the wind and drift horizontally across the surface increasing in velocity as they move. Soil particles moved in the process of saltation can cause severe damage to the soil surface and vegetation. They travel approximately four times longer in distance than in height. When they strike the surface again they either bounce back into the air or knock other soil particles from the soil mass into the air. Depending on soil type, about 50 to 75% of the total weight of soil is carried in saltation. The height of the jump varies with the size and density of the soil particles, the roughness of the soil surface, and the velocity of the wind.

11.3.5 Surface Creep: The large particles which are too heavy to be lifted into the air are moved through a process called surface creep. In this process, the particles are rolled across the surface after coming into contact with the soil particles in saltation. In this process the largest of the erosive particles having diameters between 0.5 to 2 mm are transported and around 5 to 25% of the total soil weights are carried in this fashion. Overall, the mass of soil moved by wind is influenced primarily by particle size, gradation of particles, wind velocity and the distance along the eroding area. Winds being variable in velocity and direction produce eddies and cross-currents that lift and transport soil. The amount of soil moved/transported depends on the median particles (soil) diameter and the difference in threshold and actual wind velocity. The mass of soil moved can be related to the influencing parameters by the following equation:

Quantity of soil moved $(V - V^{th})^3 / D^{0.5}$

where V = wind velocity, V^{th} = threshold velocity, and D = particle diameter.

11.3.6 Deposition: Deposition of soil particles occurs when the gravitational force is greater than the forces holding the particle in the air. This generally happens when there is a decrease in the wind velocity caused by vegetative or other physical barriers like ditches or benches. Raindrops may also take dust out of air.

11.4 Estimation of Soil Loss Due to Wind Erosion

An equation in the form of universal soil loss equation has been developed and can be used for estimating soil loss by wind. However, the evaluation of the constants in the equation for wind erosion is comparatively difficult than the universal soil loss equation. The equation is of the form,

$$E=IRKFCWDB \qquad (11.1)$$

Where, E is soil loss by wind erosion, I is soil cloddiness factor, R is surface cover factor, K is surface roughness factor, F is soil textural class factor, C is factor representing local wind condition, D is wind direction factor, and B is wind barrier factor, W is field width factor.

Another model of wind erosion estimation used in USA is as follows:

$$E=f(I,K,C,L,V) \tag{11.2}$$

Where, E is estimated average annual soil loss (t/ha/yr), I is soil erodibility index (t/ha-yr), K is ridge roughness factor, C is climate factor, L is unsheltered length of eroding field (m), and V is vegetative cover factor.

The soil erodibility index (*I*) can be estimated as given below

$$I= 525\ (2.718)^{-0.05F} \tag{11.3}$$

Where, F is % of dry soil fraction greater than 0.84 mm, K is ridge roughness factor; a measure of ridges made by tillage implements on wind erosion and can be estimated as given below

$$K_r = 0.16\ h^2/d \tag{11.4}$$

Where, K_r is ridge roughness, *h* is ridge height in mm, *d* is ridge spacing in mm, and *K* can be estimated as a function of ridge roughness.

$$K = 0.35 + \frac{12}{(K_r+18)} + (6.2 \times 10^{-6} \times K_r^2) \tag{11.5}$$

The climatic factor (*C*) depends on wind velocity and soil surface moisture. The mean wind velocity profile above the soil surface is estimated as given below.

$$U_z = \left(\frac{U_*}{k}\right) ln\left(\frac{z-d}{z_0}\right) \tag{11.6}$$

Where, U_*= Frictional Velocity

$= \tau_0$ (Shear stress at boundary)/ρ (air density, 1.2 kg/m^3) (11.7)

K = vonKarman’s constant = 0.4 (usually taken)

Z_0 = a roughness parameter

d = effective surface roughness height

Log(d) = log(h) – 0.15

$Log(Z_0) = log(h)-0.09$

c =crop height

Solved Problem:

Find out the wind velocity at 10 and 15 m height from ground surface over a wheat cropped field of plants height 1.3 m and friction velocity of 6 m/s.

Solution: The mean wind velocity above the soil surface is estimated as-

$$U_z = \left(\frac{U_*}{k}\right) ln \left(\frac{z-d}{z_0}\right)$$

Given: frictional velocity (U_z) = 6 m/s

Plants height of wheat cropped field = 1.3 m (*h*)

z = 10 and 15 m,

$$\log d = \log h - 0.15$$
$$\log z_0 = \log h - 0.09$$

Estimating d and z_0

log d = log(1.3) - 0.15 = -0.03606

d = 0.92033 m

log z_0 = log(1.3) - 0.09 = -0.023943

z_0 = 1.05668 m

Now: U_{10} = 32.26359 m/s, *and* U_{15} = 38.84401 m/s.

12	Principles of wind erosion control and its control measures.

12.1 Problem of Wind Induced Soil Erosion

Wind erosion occurs whenever conditions are favorable for detachment and transportation of soil material by wind. Five factors influence the intensity of soil erosion:

1. soil erodibility,
2. surface roughness,
3. climatic conditions (wind velocity and humidity),
4. length of exposed surface,
5. vegetative cover.

Little can be done to change the climate of an area but it is usually possible to alter one or more of the other factors to reduce erosion. Regardless of the type of procedure, the aims or principles for success in control of soil drifting are the same, in all areas where wind erosion occurs. These are

- to reduce wind velocity near the ground level below the threshold velocity that will initiate soil movement,

- to remove the abrasive material from the wind stream,
- to reduce the erodibility of the soil.

Any practice that accomplishes one or more of these objectives, therefore, will reduce the severity of wind erosion. In this section, the most common measures are described.

Wind erosion has been active in shifting soil materials since prehistoric days. In the earlier days wind erosion has not just created problems but also helped in soil formation in many regions. The activity of man accelerated the wind erosion process and it became more destructive. Deforestation, faulty method of land use, overgrazing, burning etc. are the human activities that accelerated the process of wind erosion. In India, wind erosion is said to be responsible for creation of the vast desert area of Rajasthan.

Wind erosion is a most serious problem in arid and semi-arid regions of the world. The normal annual rainfall in these regions is very low (5 to 15 cm), soil is dry and vegetation is very limited. Contrary to the general belief, wind erosion also takes place in many humid areas. The sandy soils along the rivers, lake, and coastal plains and the organic soils are removed by wind erosion. The wind erosion in such cases is more harmful as the value of the land affected is higher. Wind erosion causes several damages. It not only removes the top fertile soil but also damages crops, buildings, highways, railways, fences etc. As the finer particles are easily transported, they are removed along with organic matter and nutrients. Finally coarse textured sand particles are left and they can be more easily detached. No vegetation grows on this and the water holding capacity of soil reduces. Thus the problem multiplies. If the particles carried by the wind strike the young seedlings, they get damaged. Maintenance of channels, railways and highways become costly. Sometimes, the fertile land merges with the desert and the whole village or town may be affected due to the ingress of desert.

12.2 Types of Wind Induced Soil Erosion

Wind induced soil erosion can be classified as per the following types of soil movement.

Types of Soil Movement

Wind erosion takes place with the help of three types of soil movement. They are: (i) suspension, (ii) saltation and (iii) surface creep. All these types of movements generally take place simultaneously. The phenomenon of wind erosion is most important near the surface and major portion of the soil movement takes place within a height of about 1 m.

Suspension: Fine dust particles with diameters less than 0.05 mm are submerged in the laminar zone of air flow and therefore, they cannot be moved by direct action of the wind. The movement of these particles is generally initiated by the impact of the particles in saltation [described a little later in this Section]. Thus without saltation, the movement of the fine dust particles cannot take place. Once lifted up in the air-stream, the particles move in suspension by the turbulence of the wind.

Soils made up of very fine particles specially with diameters less than 0.01 mm are very resistant to movement. Apart from remaining submerged below the turbulent zone of wind flow, cohesive

and adhesive forces are much greater for fine particles. Specially cohesive force is high at high moisture content end when dried, the adhesive force helps them to bind together. Therefore, without saltation the movement of fine textured soil generally cannot take place. However, if some objects move over the dried surface then formation of dust particles takes place in fine textured soil and it becomes susceptible to erosion by direct action of wind.

Once the particles are lifted, their movement in suspension depends on the pattern of the wind movement. Generally they are lifted to great heights and carried to long distances. Thus they are carried away to far off distances from the place of the eroding area and are complete loss to the area. In contrast, soil moved in saltation and surface creep [also described later in this Section] gets deposited in the nearby area. Particles carried in suspension are deposited only when the wind velocity completely subsides or rainwater wets them.

Saltation: The direct action of the wind on the soil particles and their collision with other particles create somersaulting soil movement known as saltation. Major portion of the soil movement takes by saltation. The particles are pushed along the ground surface due to the wind velocity in the initial stage [Fig. 12.1]. The movement continues for some time and then descends almost in a straight line with an angle of descent in the range of 6 to 12° with the horizontal After they strike the ground, they may rebound and continue their movement by the saltation process. When the particles lose their energy by repeated striking, they may sink into the ground to form part of movement through surface creep.

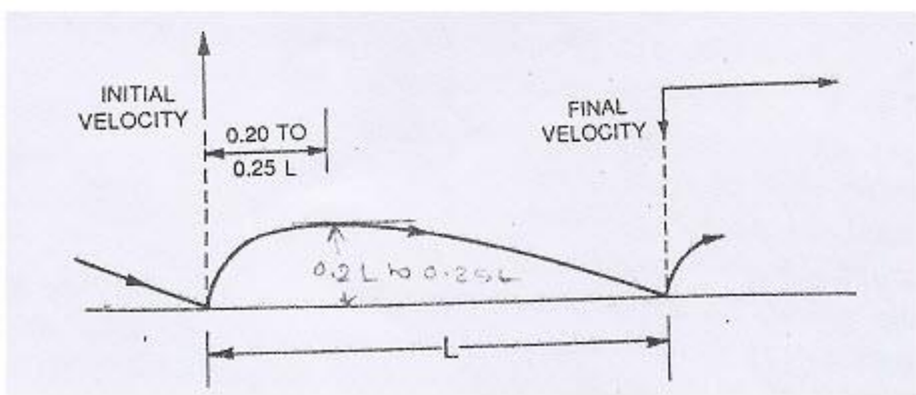

Fig. 12.1. Movement of Soil Particles by Saltation.

The initial angle of ascent of the particles in saltation is vertical but the final velocity is in horizontal direction. The particles rise to different heights and then descend at accelerated speed as a result of gravity. The vertical distance through which a particle rises in saltation is about one fifth to one forth the horizontal length of movement in a single leap. Fine grains of diameters ranging from 0.1 to 0.5 mm are mainly moved by the saltation process. The fraction of soil particles that most easily move has diameters between 0.1 and 0.15 mm. Particles of different diameters generally move at different heights.

The movement of soil by wind is not only dependent on the force of the wind acting on the particles but also on the velocity distribution of the wind to the height of saltation. The height of

movement is limited and therefore the wind velocity above certain height has no influence on the soil movement. Soil structure, surface residues, stability of structure, crusting, puddling, grading of the materials on the surface by raindrops etc., influence the soil movement.

Surface Creep: Coarser soil particles having a diameter range of 0.5 to 2 mm are too heavy and cannot be lifted up by wind action. Therefore, they can move neither by saltation nor by suspension. When the particles moving due to saltation strike them, they are pushed along the ground surface. This type of rolling or sliding of heavy particles along the ground surface is known as surface creep. Particles in saltation receive their impact energy from the direct action of the wind pressure, whereas, in surface creep the particles derive the kinetic energy from the impact of other particles moving in saltation.

Major portion of the soil erosion by wind takes place in saltation. It may vary between 50 to 75 per cent of the total weight of the soil eroded depending upon the relative size of the particles, wind velocity etc. Suspension may erode between 3 and 40 per cent; whereas, the percentage for surface creep may be between 5 to 25. Also it may be noted that suspension and surface creep are mainly initiated by saltation. Therefore, if it is possible to prevent soil movement by saltation, the other two will automatically be controlled.

12.3 Measurement for Wind Induced Soil Erosion Control

Any practice or measure that reduces the wind velocity or improves the soil characteristics is helpful to control wind erosion. Improved soil characteristics should have better structure, improved cohesive property and good moisture holding capacity. Some of the measures may provide both the requirements. Vegetation improves the soil structure and at the same time retards the surface wind velocity. In general the following practices may be adopted to control the wind erosion:

1. The soil should be covered with vegetation or crop residues as far as possible.
2. Limited cultivation should be done.
3. Dry soils should not be tilled.
4. Permanent vegetation may be established on unproductive soils.
5. After the rains, the soil may be tilled so that clod formation takes place.
6. Tillage implements should be selected in such a manner that rough surface is formed and crop residue is not buried.
7. Overgrazing should be avoided.

Principal methods of reducing surface wind velocity are vegetative control, tillage practices and mechanical methods. Vegetative control consists of cultivated crops, field and strip cropping, stubble mulching. Shrubs and trees although form part of the vegetation act as mechanical barrier to wind. Other mechanical barriers or windbreaks also may be used.

Cultivated Crops

Among the cultivated crops, close growing crops provide better protection when compared to the row of crops. Their effectiveness depends upon (i) type of crop grown, (ii) stage of growth, (iii)

density of cover, (iv) row direction, (v) climatic condition etc. Vegetation also helps to deposit the soil that is eroded from the neighboring areas. Specially, during the dry months when the soil is most susceptible to erosion, the field should be covered with vegetation.

Row crops such as maize, cotton, jowar, bajra etc., provide only partial protection. Seeding should be done in a way to provide crop rows normal to the direction of general wind direction. Crop rotation should be suitably decided to improve the soil structure and conserve the moisture. Crops suitable for such soil and climatic conditions and also capable of providing protection should be selected.

12.3.1 Stubble Mulching

When row crops like maize, bajra etc. are grown at the time of harvesting the stubble –i.e., lower portion of the stem, should be left to a certain height and the whole crop should not be harvested from the bottom. At least 10% of the rows shou1d be left standing. In case the crops are used for pasturing, the stock should be removed leaving enough stalks along with leaves to provide the necessary protection. Thus stubble mulching is the practice of maintaining crop residues at the ground surface during harvesting to resist the soil erosion. The benefits derived are:

(i) Wind velocity is retarded.

(ii) Soil blowing is physically obstructed.

(iii) Raindrops lose their energy before striking the soil.

(iv) Better absorption of rainfall takes place due to longer retention period and permeable soil structure.

(v) Evaporation loss is reduced.

(vi) Crop yield increases.

(vii) By reducing wind velocity, they can trap eroding soil from neighbouring areas.

However, the benefits accrued from stubble mulching depend upon the size of the field, velocity and relative direction of wind, quality and quantity of stubble mulching left in the field Narrow fields separated by windbreaks will be more easily protected compared to a large open field. If the crop residues can be left in vertical position, better protection can be provided. Most erodible soil may require about 10 tonnes of stubble per hectare for protection and this much crop residue may not be available from one hectare of land. During the period of fallowing, stubble mulching is most effective to provide a cover to the soil.

12.3.2 Field Strip Cropping and Contour Strip Cropping

Field and contour strip cropping consists of alternate strips of row (i.e., erosion-susceptible) crops and close growing (i.e., erosion-resistant) crops in the same field. The strip cropping is laid

out generally parallel to the field boundary or perpendicular to the erosive wind direction. The main benefits of strip cropping are:

(i) Vegetation provides physical protection against blowing of soil.
(ii) Soil erosion is limited to a distance equal to the width of the erosion susceptible crop.
(iii) Better conservation of moisture takes place.
(iv) Particles carried in saltation are trapped.

Main problems in strip cropping are:
(i) In a mechanized farm, movement of machinery becomes difficult due to narrow strips.
(ii) In case of attack by insects, there is more number of edges for protection.

The width of the strips should be selected in a way such that the farming operation is not hampered and at the same time much erosion does not take place. For example, in a sandy soil the width of the erosion susceptible crop should be limited to 6 m. But for movement of farm machinery, the width may have to be increased. In a sandy loam soil the width can be increased up to 30 m. Among the erosion resistant crops groundnut, legumes, grasses, berseem etc., that cover the ground are preferred. Row crops that permit erosion are maize, cotton, potato, bajra, jowar,.etc. Fig. 12.2 shows the field and contour strip cropping for protection of a field from wind erosion.

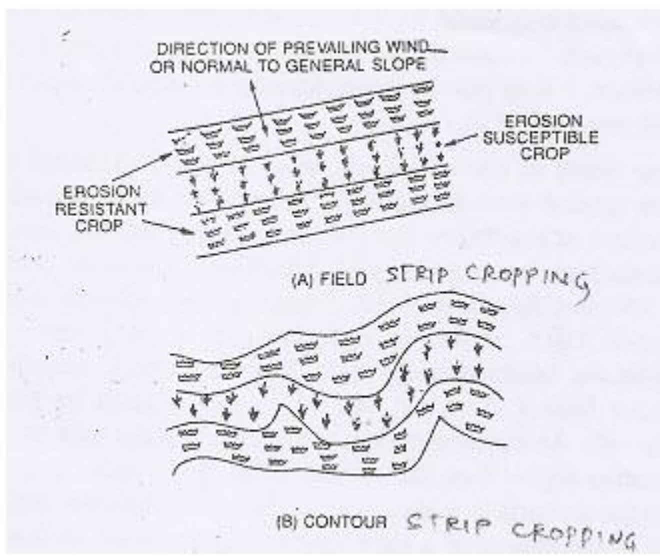

Fig. 12.2. Field and Contour Strip Cropping.

12.3.3 Windbreaks

A windbreak is defined as any type of barrier for protection from winds and refers to any mechanical or vegetative barriers consisting of buildings, gardens, orchards and feed lots. Windbreaks made up of just mechanical barriers are not very useful for field crops. However, they are frequently used for the protection of farm sheds and small areas. The mechanical barriers include brush fences, board walls, vertical burlap or paper strips. Brush matting, rock or

gravel barriers are also used as windbreaks. Some of these barriers are impermeable and others are semi-impermeable. Generally the semi-impermeable barrier are more useful as they provide better diffusion and eddying effects on the leeward side of the barrier. When vegetable crops in organic soils are required to be protected, vertical burlap or paper strips are often used. Brush matting, debris, rock, gravel etc., are more useful for stabilizing sand dune areas.

Studies of wind tunnel on the flow pattern of wind over model barriers and windbreaks indicate that the sharper barrier provides better protection compared to other shapes. The zone of influence of a rounded shape is much less than the narrow vertical shapes. The porosity of the barrier helps to extend its zone of influence downwards but may decrease the degree of protection. The wind velocity at the ground is much lower than the standard open velocity; their ratio is of the order of 0.07. Even the standard velocity may be about twice as higher compared to the surface velocity over mowed grasses. Thus the frictional drag on even vegetation reduces the wind velocity. The pull of free moving winds that pass the ends of the windbreak, can act on the sides of the stilled air mass. Thus the protection provided by the windbreak is not of rectangular shape but tends to be narrowed towards the outer limit. In addition to providing protection to the soil from wind, windbreaks have other commercial values. The tree bunches and leaves may be used as fodder and fuel.

11.3.4 Shelterbelts

A shelterbelt, usually consisting of shrubs and trees is a longer barrier than a windbreak. It is primarily used for protection of field crops, soils and conservation of soil moisture. The shelterbelt is not only useful for wind erosion control, but also saves fuel like windbreak, increases livestock production, reduces evaporation, prevents firing of crops from hot winds. In addition, it may provide better fruiting in orchards, make spraying of trees for insect control more effective.

To achieve better result in controlling the wind velocity, shelterbelts should be moderately dense from ground level to tree tops. A study on the distribution of wind velocity around the shelterbelt has shown that the wind velocity reduces significantly on the leeward side of the shelterbelt immediately after the barrier and at the central portion. At a distance of 15 to 20 times the height of shelterbelt, the wind velocity is almost equal to the velocity in the open. The wind velocity at the two ends of the barrier may be about 20 per cent greater than the velocity in the open. Therefore, long shelterbelts always provide better protection than a short one and no opening should be provided in a continuous long shelterbelt. An opening shortens the length of the belt and near it the velocity as usual becomes higher than the normal velocity. In case, it is essential to provide a road through the shelterbelt, it should be made curved. Another important point to be remembered for establishment of a shelterbelt is that it should be made as far as possible perpendicular to the direction of the most erosive wind.

Woodruff and Zingg (1952) conducted wind tunnel studies for estimation of the distance of full protection from a windbreak or shelterbelt and gave the following formula.

$$d = 17h\left(\frac{V_m}{V}\right)\cos\Theta \qquad (12.1)$$

where d = distance of full protection, m

h = height of the barrier, m

V_m = actual wind velocity at 15 m height, m/s, and

q = the angle of deviation of prevailing wind direction from the perpendicular to the barrier.

From the wind erodibility of farm fields, Chepil (1959) concluded that the velocity (V_m) at 15 m height required to move the most erodible soil fraction was about 9.6 m/s. This is valid for a smooth bare surface after the initiation of erosion and before formation of surface crust by rainfall. In fact, Equation 12.1 is valid for wind velocities up to 65 km/h. While deciding the width of crop strips, the same equation may be used by substituting crop height as the height of barrier.

A shelterbelt will be more effective if a combination of low, medium and, tall trees is used as shown in Fig. 12.3. This helps to provide a compact and dense barrier. Generally shrubs of low height should be grown on the windward side. Tree species of low branches may be placed at the middle and tall trees with high branches on the leeward side. But such a multiple row shelterbelt occupies large land area. Suitable varieties of trees should be selected for the specific location. For the desert areas of Rajasthan trees like Neem (Azadirachta Indica), Anacardium Occidentale, shrubs like Sisal (Agave Americana) etc. are commonly used.

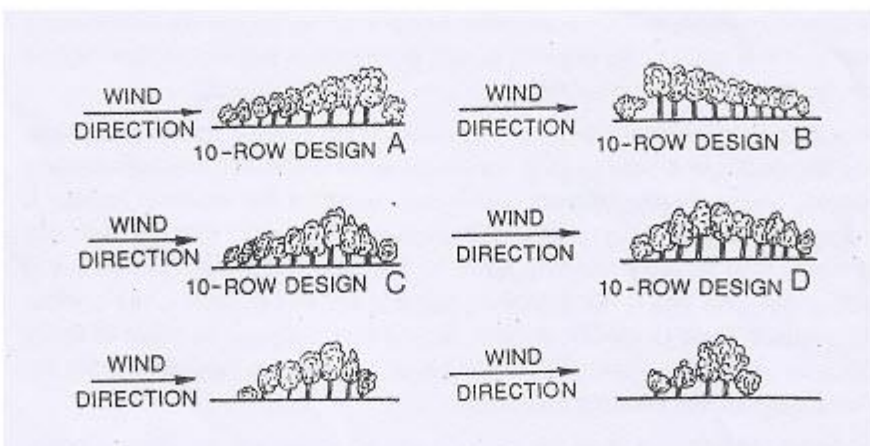

Fig. 12.3. Side View of Tree Arrangement in Shelterbelts.

12.3.5 Other Tillage Practices

Other tillage practices -if properly adopted, can reduce the wind induced soil blowing to a great extent. Similarly, faulty tillage operations increase the soil erosion by wind. If the soil is pulverized and the crop residues are buried due to tillage operations, erosion problem increases. The effective way of prevention of wind erosion is by producing a rough, cloddy surface and

exposing the crop residues on the surface. If the land is ploughed at optimum moisture content after the rains, big clod and large aggregate formation takes place.

If by tillage practices, small ridges perpendicular to the direction of the wind can be formed then significant control is possible. In case the surface soil consists of mainly sandy soil underlain by fine textured clayey soil, tillage may give some immediate benefit. The sand being more erodible should be buried and resistant clayey soil be brought to the surface. Efforts should be made to grow vegetation at the earliest. Otherwise this may not be effective for a long period. The clay may also provide cloddy structure on the surface. Generally, these types of tillage operations are Very costly and should be taken up only when other better alternatives are not immediately available. If vegetation is grown, the organic matter produced in the soil by the vegetal cover can serve the same purpose in addition to providing other benefits.

As discussed earlier, stubble mulching provides a good control for wind erosion. This is specially important in a year of crop failure or when sufficient vegetative cover cannot be produced. Sweep furrow openers which can cut under the material, leaving it in almost standing position are very effective implements. One-way disc plough also leaves the crop residues in partially standing position. Mould board plough turns the soil and buries the crop residues and is not therefore, suitable for this purpose. Again when it is required to produce a rough cloddy surface, mould board plough is suitable under an optimum moisture condition. Vertical disc plough or harrows are suitable neither for retaining crop residues nor for creating cloddiness.

Other important implements used for ridging and clodding are the lister plough, shovel or sweep cultivator, deep-furrow drill, spring-tooth harrow etc. Mould board plough, subsoiler, lister, disc plough and grading machines can bring the subsoil to the surface. When straight or V-shaped blades or rods are used as subsurface tillage implements, they can undercut without disturbing the surface or the residues. Obviously, the clods cannot be formed on the surface by these tillage implements.

It should however, he remembered that tillage practices offer only temporary and urgent controls and may have to be repeated. They are quite costly and should not be used as a general practice. They cannot act as substitutes for the vegetative covers which provide long term and multiple benefits. Therefore, other tillage practices should be used only as emergency measures when no other method is immediately effective.

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